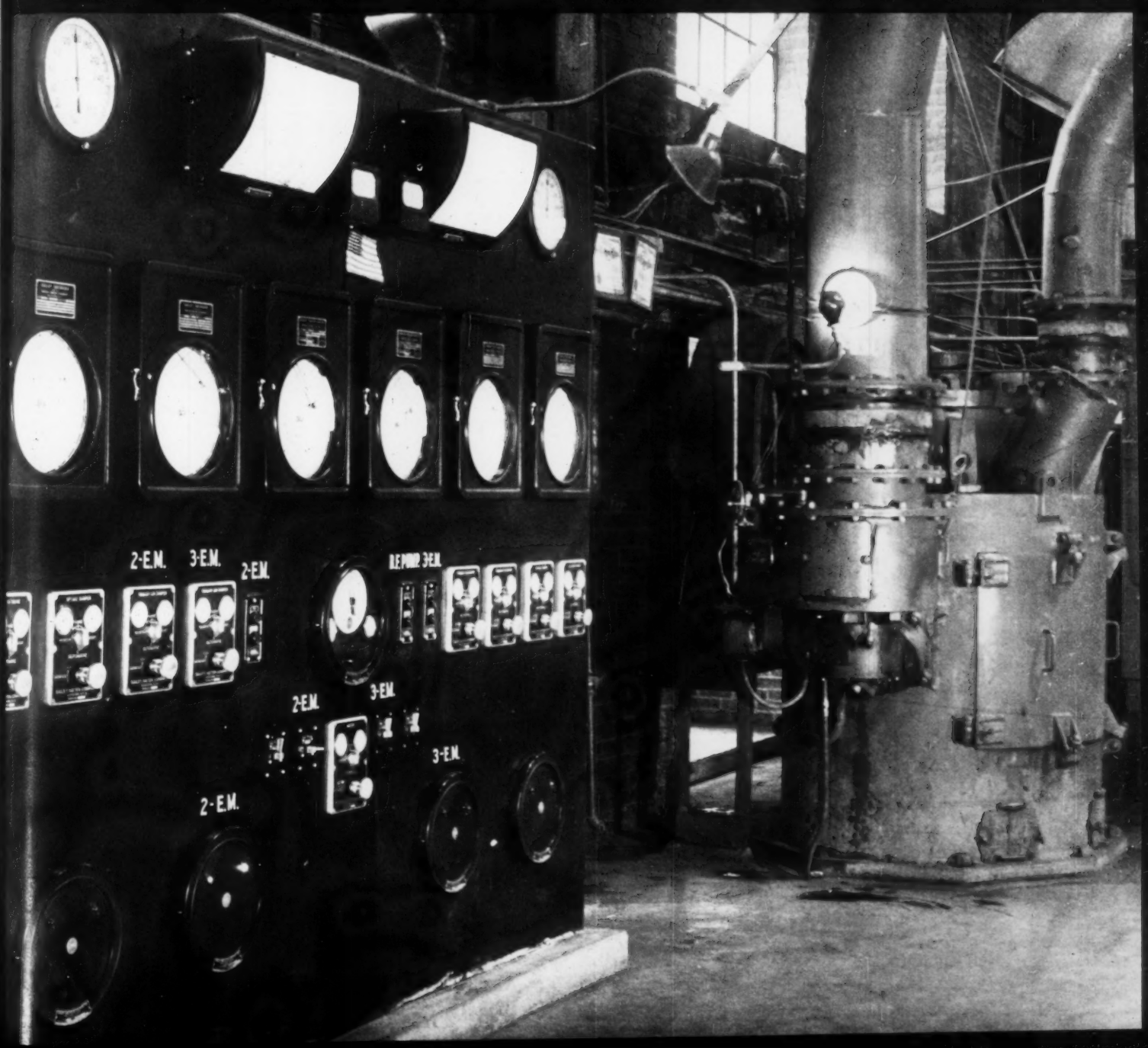
Instruments

THE MAGAZINE OF Measurement and Control

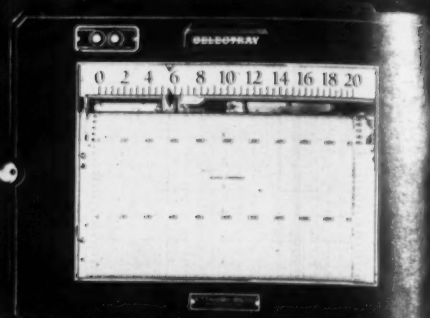
Vol. XIII
DEC. 1940
No. 12



THERE IS A CELECTRAY FOR EVERY LABORATORY and INDUSTRIAL PYROMETER REQUIREMENT

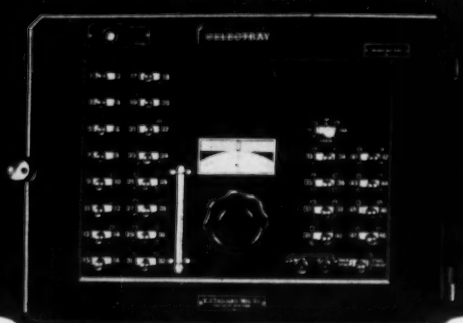
CELECTRAY RECORDER CONTROLLER
for Throttling Electric Heat

CELECTRAY
6-Point INDICATING CONTROLLER
Also made for 3, 4 and 5 Points



CELECTRAY RECORDER CONTROLLER
for Throttling Fuel Heat

CELECTRAY Single Point INDICATING
POTENTIOMETER CONTROLLER



CELECTRAY Multiple Point
MANUALLY BALANCED INDICATOR

CELECTRAY Multiple Point
SELF-BALANCING INDICATOR

The CELECTRAY principle of potentiometric measurement and control of temperatures has been reduced to practice in many laboratory and industrial applications. Because, the most compelling feature of this notable line of Pyrometers is expressed in terms of their contribution to more precise and economical plant operation.

Today, a new CELECTRAY Controller is providing an economical means for throttling electric heat with no other equipment than is ordinarily used for on-and-off control. This new Controller has no dead zone, and holds a steady temperature without oscillation.

The TAG method of photoelectrically balancing a potentiometer or Wheatstone bridge means higher recording accuracy, increasing the value of CELECTRAY as a precise electrical instrument.

The CELECTRAY Pyrometers shown here include most of the newer models for indicating, recording and controlling. We urge you to get the whole story on these rugged modern instruments . . . learn what their matchless sensitivity, speed and adaptability can do for you in lowering operating expense and raising product uniformity.

CELECTRAY Vibration-Proof
INDICATING CONTROLLER

CELECTRAY 96-Point SWITCH BOX

CELECTRAY
Two-Point INDICATING
POTENTIOMETER CONTROLLER

C. J. TAGLIABUE MFG. CO.

Park & Nostrand Ave's., Brooklyn, N. Y.

TAGLIABUE BROOKLYN N.Y. U.S.A.

NOT 1 BUT 5

You Can Get **Not 1 but 5 Forms of Control** in the **NEW TAYLOR FULSCOPE CONTROLLER**

THE NEW Taylor Fulscope Controller is unique. It can *grow* in your plant. It can grow as your processing needs grow. At first your processing needs may be simple, so you install the simplest form of the new Fulscope. As time goes on, perhaps your production expands, and your processing operations become more demanding. You need a different controller. What to do? Buy another instrument? You don't need to! Another unit assembly may be added to or substituted in your basic Fulscope Controller. That converts it into the controller your progressing needs require. You see, merely by adding or substituting such unit assemblies in the drilled and tapped Fulscope cases, it's possible to expand the Fulscope Controller to give all types of process control—from simple *fixed high sensitivity*, through *adjustable sensitivity*, *adjustable sensitivity with automatic reset*, to *adjustable sensitivity with Pre-Act*, (Taylor's amazing new control effect based on rate of control-point deviation) and *adjustable sensitivity with automatic reset and Pre-Act*, the ultimate in process control. You may never need such advanced control, but Taylor has it if you want it. The new Taylor Fulscope Controller is industry's 5-in-1 controller for *all* kinds of process control.

There's a national need today for this astonishingly versatile, adaptable Fulscope Controller. Industry's biggest job is helping America prepare fast. You must be prepared to produce top quality at top speed. With this new Taylor Fulscope Controller in your plant, you *are* prepared. No other process controller is so completely new—none has been so completely redesigned (not just tinkered with)—no other is so easily adaptable to growing, changing processing needs. Your own preparedness program can well begin with the new Taylor Fulscope Controller.

Ask the Taylor man what the 5-in-1 features of the new Fulscope mean specifically to *you*. Find out about the recording and indicating types—for temperature, pressure, flow, and liquid level. Learn about the new Taylor Recorder, twin of the Taylor Fulscope Controller. *Now*—from Taylor Instrument Companies, Rochester, N. Y. Plant also in Toronto, Canada.

Not 1, but all these 5 Forms of Control Available in the NEW TAYLOR FULSCOPE CONTROLLER

Fixed High Sensitivity—Adjustable Sensitivity—Adjustable Sensitivity with Automatic Reset (in same case)—Adjustable Sensitivity with Taylor's unique Pre-Act effect Adjustable Sensitivity with Automatic Reset and Pre-Act

All Fulscope Controller cases are drilled and tapped to permit adding or substituting different forms of control—easily, right in the field!

BE PREPARED with TAYLOR INSTRUMENTS

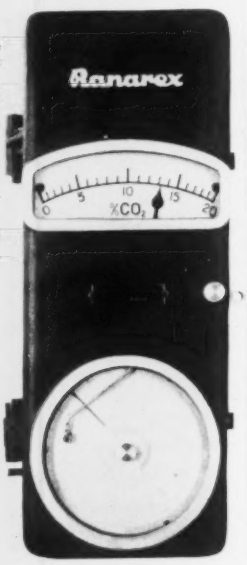
Taylor

Indicating Recording Controlling

TEMPERATURE, PRESSURE, FLOW *and* **LEVEL INSTRUMENTS**

Chicago building SAVES $781 PER YEAR on fuel with "RANAREX"* CO_2 Indicator and Recorder!

As a direct result of installing a Ranarex CO_2 Indicator and Recorder, The Real Estate Corporation, Managers of the Times Building, Chicago, report *annual* savings of $781 on fuel—more than twice the purchase price of their Ranarex equipment.



H. EDSALL OLSON, President, writes: "We have in this building two hand-fired 200 horse-power marine-type boilers. Two years' operation under Ranarex has disclosed a saving of 146 tons of coal per year. Translated into dollars that means a saving of $781.10 per year."

LET RANAREX CUT *YOUR* FUEL COSTS, TOO!

It's easy to cut fuel costs with an all-mechanical Ranarex CO_2 Indicator and Recorder! You get readings almost instantly. You get them constantly—a continuous 24-hour record. No chemicals, orifices or fragile parts! Operates on lighting circuit. Get free booklet showing how well-known firms have saved up to 20% on fuel. Write to The Permutit Company, Dept. A8, 330 West 42nd Street, New York.

RANAREX
Product of PERMUTIT

*TRADEMARK REG. U. S. PAT. OFF.

Instruments
THE MAGAZINE OF MEASUREMENT and CONTROL

Vol. XIII DECEMBER 1940 No. 12

FRONT COVER: Control board for two 110,000 lb. hr. pulverized-coal-fired boilers at Libby-Owens-Ford Glass Co., Toledo, Ohio.
Courtesy Bailey Meter Co.

EDITORIAL 377

NEW INSTRUMENTS 378
Indicators, recorders, controllers, inspection devices, etc., for plant, field and laboratory.

OPTICAL PYROMETRY 383
Chapter XI of "Temp. Meas. & Control" in full
By M. F. Béhar

INDUSTRIAL INSTRUMENTATION COURSE 396
Starts in February, at Case School
(Announcement)

SOME ABC'S OF CONTROL 397
—of automatic temperature control
By M. F. Béhar

ADAPTING A D.C. GALVANOMETER TO AN A.C. BRIDGE 404
By Philip Ewald

MANUFACTURERS' NEW LITERATURE 408

ADVERTISERS' INDEX 406

Published Monthly on the 15th by
THE INSTRUMENTS PUBLISHING COMPANY
1117 Wolfendale Street, Pittsburgh, Pa.

RICHARD RIMBACH, Managing Editor
M. F. BEHAR, Editor

BRANCH OFFICES

Boston: James Condon, 36 Myrtle St. (Lafayette 0829).
New York: R. K. Farnham, 56 W. 45th St. Room 1105 (Murray Hill 2-8763)
Chicago: William Farnham, 201 N. Wells St. (Andover 4180).
Cincinnati: Harold W. Haskett, Keith Bldg. (Parkway 7639).

Annual Subscription: U. S. $2.00. All other countries $3.00 *payable in advance* (remit by New York draft).

Copyright 1940 by The Instruments Publishing Company.

Entered as second-class matter January 26, 1932, at the post office at Pittsburgh under the Act of March 3, 1879.

Instruments

THE MAGAZINE OF *Measurement and Control*

M. F. BEHAR, Editor

Industrial Instrumentation Comes of Age

IN line with the long-standing policy set forth in last month's editorial, *Instruments* is happy to assign half a page to the announcement of an evening course in Industrial Instrumentation, given at Case School of Applied Science, which starts next February. After reading Professor Miller's tentative schedule (page 396) you will know as much about the details of this course as we do. Nevertheless it is safe to assert that this course owes its raison d'être to *Instruments*. Let's look at the record.

To the best of our knowledge this is the most elaborate course of lectures on Industrial Instrumentation ever announced by an engineering school—except of course last year's announcement of a course of fifty-six lectures at Carnegie Tech. That course had to be cancelled because the one who was to have been in charge fell ill before its start and was flat on his back for three months.

It may be remembered that in our April 1940 issue there was announced a *day* course in Industrial Instrumentation in the Department of Mechanical Engineering of the Oregon State College (Professor S. H. Graf in charge). For the convenience of those interested, we reprint here the seven main headings of the Oregon course:

1. Review of basic standards; 2. Elements used in measuring devices; 3. Industrial measuring instruments; 4. Process control; 5. Examples from industry; 6. Precision of measurement and control; 7. Calibration and maintenance.

Since the evening course which was to have been given at Carnegie Tech represented a study of the needs of this district's industries, we give its main headings:

1. General introduction; 2. Basic principles and generic properties; 3. Automatic control principles; 4. Automatic controller classes and characteristics; 5. Electrical instrument classes and characteristics; 6. Temperature; 7. Pressure; 8. Rate-of-flow; 9. Positive liquid and gas metering; 10. Gas and pH analysis; 11. Automatic combustion control.

Dr. Draper's now-famous M.I.T. instrument course is perhaps more aeronautical than industrial. Interested readers may "sample" it from the article by him and Dr. Schliestett in our May 1939 issue.

Searching the files of *Instruments*, we find that the first announcement of an engineering school instrumentation course to which we gave space (Jan. 1934 issue) was a day course at Columbia University:

A course in instruments is the first laboratory course given to our Mechanical Engineering students. On account of the short time allotted to this subject they can do little more than study instrument principles . . . new curriculum will include a revised course in Instrument Laboratory, followed by a one-term, three-hour-per-week lecture course on Instruments and Controls. These two courses will be required for Mechanical Engineering students and open to others properly qualified . . . will be largely qualitative. A more advanced course will . . . deal with quantitative analysis of existing apparatus.—H. L. PAGE, Prof. of Mech. Eng.

The first fairly-complete outline of the scope of industrial instrumentation was in the form of a three-page table which appeared in the November 1930 issue of *Instruments*. We had prepared that table at the request of *Instruments* (that was before we became editor) and in our introduction to it we explained:

. . . The scientific instrument of yesterday is the industrial instrument of today. . . . Today there are no industrial instruments pertaining to hardness, all of them being testing instruments. Tomorrow . . . we may witness the production of bar and sheet stock whose hardness is controlled not in the laboratory but automatically during production . . . Inasmuch as I wished to avoid the rôle of dictator and remain a reporter, this tabulation not only covered known industrial instruments but allowed for coming developments, in the way of industrializing present-day laboratory testing and scientific instruments.

In 1927, when industrial automatic controllers were written up for the Fourteenth Edition of the *Encyclopaedia Britannica*, "the powers that were" did not like the word Instrumentation. They said it was a musical term. They re-titled our article "Regulation, Automatic." They were not alone: *we* were alone! In fact, even the before-1927 contributors to "The Engineers' Handbook of Industrial Instruments" would probably have declined to aid such a fantastic project as a "Manual of Instrumentation." In those days there was only a vision and a prophecy—the prophecy being universally met by scoffing . . . although it has come true, for today there *are* instrumentation societies and there *are* instrumentation courses!

Anyway, it doesn't matter much. The main thing is that the dreams could not have come true if there had been in another city another vision—a practical vision—if there had not appeared in January 1928 in the City of Pittsburgh, the first issue of a magazine then called *Instruments Industrial—Scientific*, which name became, beginning with the January 1932 issue, the one you see at the top of this page. And now, one hundred and fifty-six consecutive issues of THE magazine of measurement and control have come out. To say that each issue has "enriched American civilization." and all that sort of thing, would sound extravagant. However, as *Instruments* concludes its thirteenth year of service, attention may be called to the fact that there have been tremendous advances in the fields to which it is devoted—not only in the establishment of instrumentation courses but:

—in the useful applications of instruments, meters, automatic controllers, inspection and testing devices, etc., throughout industry;

—in their diversification, standardization and quality;

—in the formulation of the theories underlying proper selection and correct application of these products;

—in "the recognition of Instrumentation as a distinct branch of engineering and as a distinct field of scientific management"—even by some groups jealously antagonistic in the past (but now climbing on the bandwagon);

—in the publication of authoritative texts on the several distinct branches of Instrumentation;

—in the organization and management of instrument departments;

—in the training of instrument apprentices, instrument engineers, etc.;

—in the influence and standing of instrument men;

—in the economic status of all instrument men, from young instrument apprentices to instrument-minded high executives whose titles do not include the word "instrument";

—and in the manifold blessings to American civilization thereby brought about.

THE COUNTER READS

0 0 1 5 6

and thereby registers the end of the thirteenth year of *Instruments*' service to users of measurement and control devices—to all of whom we wish a Merry Christmas and a HAPPY NEW YEAR

BAILEY CONTROL METER SYSTEM

The Mark of

Effective Control

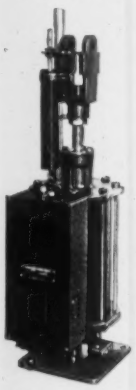
Process Control for sensitive, stable automatic control of temperature, pressure, liquid level, flow and other factors as applied to industrial processes. Responds to changes quickly, without overtravel or hunting. Ask for Bulletin No. 101.

Combustion Control that is simple but *complete* for providing economical operation of boilers of 200 h. p. and larger. Details in Bulletin No. 102.

Recorder-Controller

Boiler Meters for recording combustion conditions and guiding boiler operators. Described in Bulletin No. 44.

Multi-Pointer Gages for indicating factors such as draft, pressure, temperature and speed. These Gages are available with any number of pointers and any scale combination; in either the oil sealed bell or diaphragm construction.



Control Drive

Flow Meters for indicating, recording and integrating the flow of steam, water, sewage, air, gas and other fluids. Bulletins No. 39 and 300.

Recorders for pressure, temperature, drafts, liquid level and other factors.

G-3

BAILEY METER COMPANY

1041 Ivanhoe Rd., Cleveland, Ohio

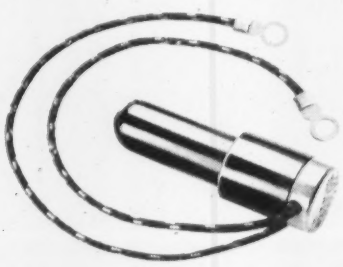
THE MONTH'S NEW INSTRUMENTS

In this department we strive to report each month ALL the new devices for measurement, inspection, testing, metering and automatic control.

When writing to manufacturers directly, please mention this department as your source of information. Or write to Information Section, Instruments Publishing Company.

Mercury Switches

Two new unbreakable mercury switches, "No. A-5M" and No. A-10Z," can carry greater currents than maker's regular switches with the same dimensions. Stand-



ard "A-5" is rated for 200 watts a.c. lamp load at an operating speed not to exceed 20 times per minute; new "A-5M" (same dimensions as A-5) withstood 750,000 operations on a 500 watt a.c. lamp load at 5 times per minute 24 hours a day; also 50,000 operations on a 1,000-watt d.c. lamp load at 25 times per minute. Performance of the A-10Z is equally impressive when compared to a standard A-10 identical in dimensions. The A-5M is adapted to snap-acting mechanisms, as well as tilt action; can be used in many applications which formerly required the A-10 (10-amp. switch.) Similarly, the A-10Z can be used in many applications where formerly the capacity of the A-10 was not enough and the A-20 (20-amp. switch) was required.—*Durakool, Inc., Elkhart, Indiana.*

Circuit-calculation Device for Equalizer Design

The McProud "Quadget" is intended to simplify the design of constant impedance equalizers, specifically for 500-ohm circuits. However, it is possible to adapt the values given to circuits of any other impedance. On the face of the "Quadget" are charts showing the transmission characteristics of the equalizers and suppressors for which values are given. Also, the configuration of the various networks are shown, along with the values. Place the desired resonant frequency adjacent to the letter indicating the shape of curve required, and the values are shown for the elements of the network. These values are designed for curves of the shapes shown when the pad loss is 10db. For other pad losses, the constant k_1 shown on the reverse along with the resistor values for the required pads are used as shown. For circuits of impedances other than 500 ohms, conversions may be made in accordance with the information supplied on the face of the device. All values for inductances are in henries; for condensers, in microfarads.—*Norman B. Neelu, 5334 Hollywood Blvd., Hollywood, Calif.*

Frequency Meter

New vibration frequency meter weighs 8 oz., is no larger than a slide-rule, but can indicate what frequencies between 500 and 20,000 c.p.m. are present in a vibrating

body. Employing the vibrating-reed principle, it consists of a thin spring-steel vibrator clamped at one end between a set of steel rollers. A knurled knob connected to the rollers permits their rotation, and moves the steel reed in or out, changing its frequency. A sliding pointer on the back end of the reed indicates the vibrating frequency which is read on a scale on the frame of the instrument. To use the meter, its head is held against the vibrating body and the adjusting knob rotated until the reed vibrates at maximum amplitude. If more than one vibrating frequency exists, there will be a point of maximum amplitude for each, and vibrations in differing planes may be detected by changing the axis of the meter. The meter will indicate a vibration whose double amplitude is 0.0001" or greater. It can measure harmonies of basic vibration frequencies. Although not designed to measure the amount of vibration, it may be used as a rough indicator of its magnitude. It is said that the meter will stand all normal rough treatment without losing its calibration. Because all moving parts are direct connected, i.e., no gears or gearing employed, backlash is non-existent in the adjusting knob, and the indicating scale.—*Westinghouse Elec. & Mfg. Co., Research Products Dept., Radio Div., Baltimore, Md.*

Sodium Lamp Controller

A Novalux controller has been announced for use in experimental, laboratory, or spectacular lighting applications of the 10,000-lumen, Type NA-9 sodium lamp. It is available for multiple-circuit a-c. operation only. Composed of a compact cast-iron case equipped with simple brackets, the controller has a terminal board readily accessible, with an "on" and "off" control switch; other operations are automatic. The controller comes equipped with 15 feet of 4-conductor rubber-covered cable to permit operation of the sodium lamp at distances up to 15 feet from the controller. It is suitable for indoor or outdoor use.—*General Electric Co., Schenectady, N. Y.*

UP TO

3,666,666 OHMS per VOLT!

Negligible Voltmeter Loading

No Ohmmeter Resetting

NEW RCA JUNIOR VOLTOHMYST

Here is a D.C. *Electronic* push-pull Volt-Ohmmeter, using the famous Rider VoltOhmyst circuit—*plus* a convenient isolated A.C. 1000 ohms-per-volt Rectifier-type Voltmeter—all at a price scarcely higher than the price of an ordinary volt-ohmmeter!

Constant input resistance of 11,000,000 ohms on D.C. Voltmeter ranges of 0-3, 10, 30, 100, 300, 1000 volts—permits checking A.V.C. and A.F.C. voltages, and oscillator grid-bias voltages under actual operating conditions *with the signal present*, through an isolating 1-megohm signal-tracing probe! Sensitivity is as high as 3,666,666 ohms per volt!

As an ohmmeter, too, this new RCA test instrument gives accurate resistance-readings . . . from 0.1 ohms to *1000 megohms*, in 6 Decade steps. No zero resetting is necessary when changing scales. See the RCA Junior VoltOhmyst at your RCA Distributor's.

Over 580,000,000 RCA Radio Tubes have been purchased by radio users . . . in tubes as in test equipment and accessories it pays to go RCA All the Way.

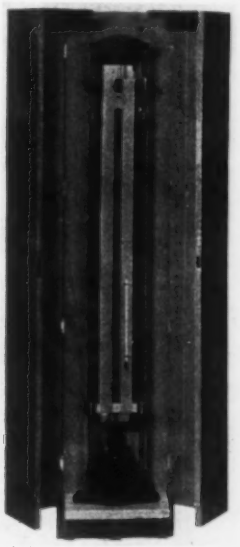
RCA Test Equipment

RCA Manufacturing Co., Inc., Camden, N. J.

A Service of the Radio Corporation of America

Altimeter Testing Barometer

New "No. 35" altimeter testing barometer consists of a mercury tube, two silvered brass scales, and a cistern with a suitable hose connection. The left-hand



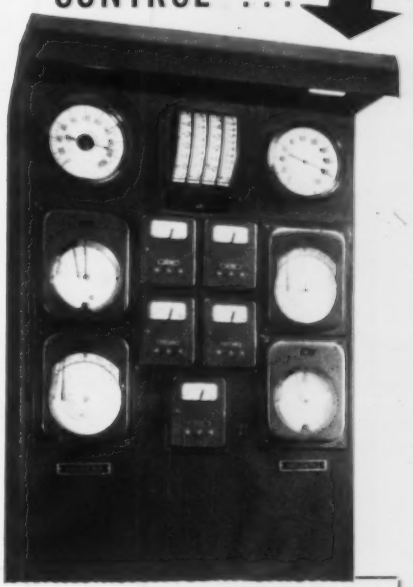
scale is graduated in tenths of an inch from 6.50" to 31.50" with sliding vernier reading to 0.01"; the right-hand scale is blank but mounted thereon in the lower portion is a 7¼" stem graduated and figured thermometer ranging from 10° to 120° F. in single degrees, figured every 10°. Scales are adjustable to ± 500 feet. Instrument is permanently mounted in a mahogany case with a center-opening double door. To facilitate easy reading, there is mounted therein an opal glass reflector the full distance of the scales.—*Henry J. Green, 1191 Bedford Ave., Brooklyn, N. Y.*

Roll-type Chart for Attaching to Testers

Incorporation of a roll-type tube chart as a built-in feature of some new tube testers increases their appearance, speeds up tube testing and obviates the use of sepa-

rate charts. These same advantages can be provided for many older tube testers by new "Rolindex" tube chart which, mounted in its own 11" × 3¾" × 3" hardwood case, can be easily attached to existing tube-testing equipment. Unit consists of a mechanical movement driving the roller chart and actuated by a knurled disk projecting edgewise through the front panel. Set into this panel is a window of transparent plastic with a horizontal hairline engraved across its center to guide the eye across the columns of test-control settings. Chart roll is renewable: up-to-date charts will be available from R.C.P. as new tube types require. Numerous charts are now available. "Rolindex" is supplied in two models: Model 102 with internal illumination, Model 101 without.—*Radio City Products Corp., 88 Park Place, New York City.*

HERE'S Hays CENTRALIZED COMBUSTION CONTROL . . .



HAYS is the one truly CENTRALIZED control system—All of the control and measuring instruments are contained in one panel. Here is concentrated all information necessary for an intelligent understanding of what is going on inside the furnace, boiler and steam lines. And from this central panel the entire control system or any individual part of it may be operated manually.

Hays Centralized Combustion Control is offered through capable engineering organizations located in all principal cities of the U.S.A. and Canada. Correspondence is invited. Send for our 40-page catalog. Write to 925 Eighth Avenue, Michigan City, Indiana.

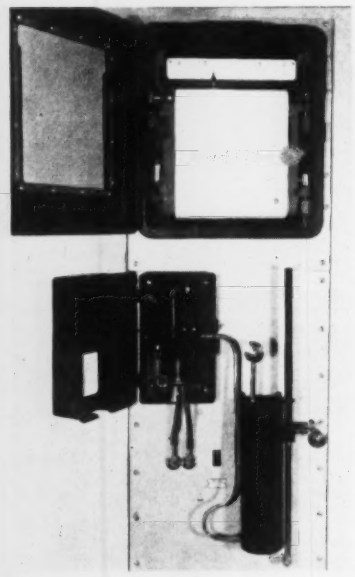
The HAYS CORPORATION

COMBUSTION INSTRUMENTS AND CONTROL

MICHIGAN CITY, INDIANA, U.S.A.

Dissolved Oxygen Recorder

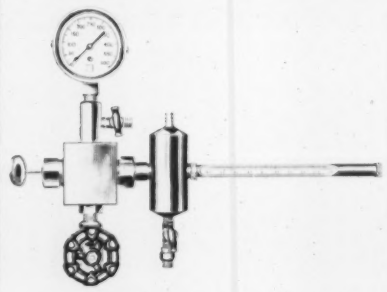
Designed for use by operators of large steam plants, new Cambridge Dissolved Oxygen Recorder has a sensitivity such that dissolved oxygen in feed water can



be measured to one part in 100,000,000. It is completely automatic and provides a continuous indication and record of dissolved oxygen entering the boiler. It has a range of 0 to 1 part of dissolved oxygen per 1,000,000 parts of water. It records full scale upon a chart 10" wide. Readings of 0.01 part of dissolved oxygen per 1,000,000 parts of water may be readily determined since they will scale 0.1" on the chart. Readings of 0.003 parts will scale nearly 1.32" on the chart. Operation of the instrument's metering unit is based upon the thermal conductivity principle wherein four platinum spirals forming four arms of a Wheatstone bridge are employed. Water to be analyzed enters a cooler-regulator where it is reduced in temperature and maintained at approximately 85° F. A constant head device maintains the correct flow of water through the scrubbing tower of the analyzer unit. Hydrogen is generated in the electrolytic cell and flows to the scrubbing tower where it comes into intimate contact with the sample water. The water dissolves some of the hydrogen and gives up part of its oxygen. The resultant mixture of gases diffuses to the meter block which contains the measuring elements: four platinum spirals connected in the form of a Wheatstone bridge which are heated to a definite value by the current flowing through them. Two of the spirals are exposed to the sample gas and two are permanently sealed with saturated hydrogen. When pure saturated hydrogen surrounds the exposed spirals the bridge is in balance and no deflection of the recorder occurs, thereby indicating zero oxygen. When the exposed spirals are surrounded by a mixture of hydrogen and oxygen their temperature will increase due to the lower thermal conductivity of the mixture. This causes a change in resistance of the spirals with a consequent unbalance of the bridge circuit. The deflection of the recorder is, therefore, proportional to the concentration of dissolved oxygen in the sample water passing through the scrubbing tower.—*Cambridge Instrument Co., Inc., 3732 Grand Central Terminal, New York City.*

Automatic Timer

Principal features of new Bacon Automatic Timer are: mercury-to-mercury contacts enclosed in unbreakable metal tubes; one moving part; self-starting and self-oiling clock movement. Time ranges are available in hours, minutes or seconds.—*Emra D. Bacon, 7514 Brooklyn Ave., Cleveland, Ohio.*



DEW POINT TESTER

FOR HIGH PRESSURE GASES

Bureau of Mines Type

Simple to operate and accurate in results.

This apparatus for the accurate determination of the dew point of gases under pressure was developed by the Bureau of Mines and is described in its Report of Investigations 3399.

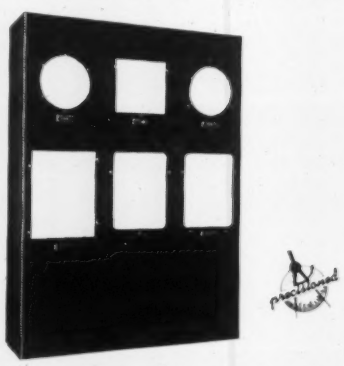
Manufactured and Distributed by

The REFINERY SUPPLY CO.

631 E. 4th Street, Tulsa, Okla.
1309 Capitol Ave., Houston, Tex.

Write for literature.

FALSTROM



STEEL PANELS

FALSTROM Precisioned Steel Panels are specified by engineers for their Strong Construction . . . Adaptability . . . Fine Appearance . . . for use in—

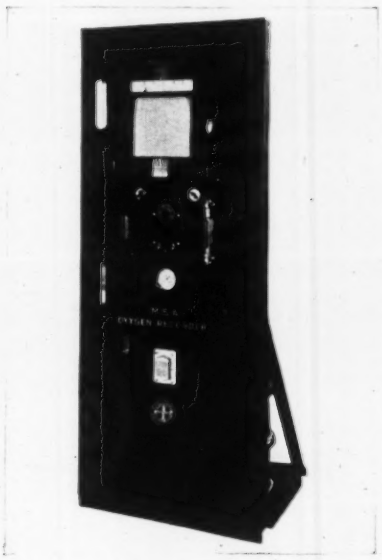
POWER PLANTS
OIL REFINERIES
PUBLIC UTILITIES
PROCESS INDUSTRIES
COMMUNICATIONS

Send blueprints. Write for bulletin P-12

FALSTROM COMPANY of PASSAIC N. J.

Oxygen Recorder

New "M.S.A. Oxygen Recorder," available completely assembled on a 7-ft. high steel panel, is for measuring and recording oxygen in other gases, and is said to



be the only instrument of its type made in America. It measures oxygen concentrations from 0 to 20.8%; and can be calibrated for any range desired within these limits. Recorder is principally a voltaic cell, made of cast hard rubber, containing an electrolytic solution which is a strong reducing agent, and two electrodes of pure copper. One electrode, in the form of a bar, is completely immersed in the electrolyte; the second, in the form of a ring, slowly revolves with approximately half of its periphery submerged in the electrolytic solution. As the surface of the copper electrode revolves out of the solution, oxygen in the sample reacts with the copper to form copper oxide. With continued rotation the copper oxide is submerged in the solution and then a potential is set up between the copper oxide and the negative copper electrode. This potential is not influenced by the rate of sample flow and is proportional to the amount of oxygen in the sample. Other advantages claimed are: all conductors carrying sample and solution are of hard rubber; clear plastics are used instead of glass where transparency is required; construction of the electrical control box excludes corrosive gases; electrical parts and conductors are enclosed in explosion-proof fittings; CO_2 and other acid gases can be removed from interference with operation, when necessary, by a caustic scrubber.—*Mine Safety Appliances Co., Braddock, Thomas and Meade Sts., Pittsburgh, Pa.*

Hydraulic Booster Pump

A new motor-driven hydraulic pump capable of developing pressures up to 6,000 lbs./in.^{2} is especially applicable for use in creating high test pressures for catalytic hydrogenation work, for determining the bursting strengths of cylinders, spheres, etc., for operating high-pressure and hydraulic intensifiers, and for determining the effects of high pressures and their sudden release on various materials. It consists essentially of a geared-head motor (for operation on 115 or 230 volts a-c. or d-c.), reservoir and compression chamber, mounted on a substantial cast iron base. Theoretical displacement per hour, 553 cu. in. Working volume of the reservoir, 1300 ml.; actual volume 3000 ml. Working and actual volumes of the compression chamber, 1300 ml. Tested to 9000 lbs. in.^{2}.—*American Instrument Company, Silver Spring, Md.*

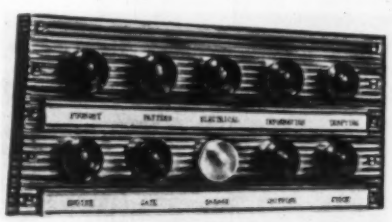
Vacuum-tube Voltmeter

New "Model 62" operates on 115-v, 60-cycle supply, weighs approx. 6 lbs., is accurate to 2% of full-scale on each range. (1) D-c. Voltmeter: Stabilized, balanced,

degenerative amplifiers eliminate zero drift—no change of zero with range selection. High input resistance—less than 10^{-8} amp. grid current on all ranges. Provision for reversal of polarity—convenient in taking discriminator curves, etc. Linear scale calibration on all d-c. ranges. (2) A-c. Voltmeter: Balanced diode circuit eliminating zero drift on a-c. ranges. Low-loss, low capacity probe designed for minimum loading at high frequencies. Blocking condenser to separate a-c. from d-c. potentials applied to probe. On a-c. the instrument is a peak voltmeter calibrated to read r.m.s. values of a sine wave or 71% of the peak value of a complex wave. Pushbutton Selection of Five Ranges: 1, 3, 10, 30, 100 volts full scale either a-c. or d-c.—*Measurements Corpn., Boonton, N. J.*

Mounting Strips

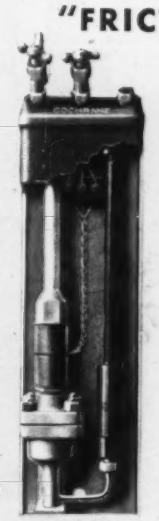
Facilitating the use in multiple of signal-lights, toggle-switches, and push buttons, new standardized mounting strips said to have wide application in the signal, con-



trol, and general annunciator fields, are not unlike those used in the construction of telephone switchboards, etc. They are of stainless steel, rippled finish, and have beveled ends. A strip is furnished with all devices mounted on it ready to install and place in service. Strips are available in three lengths, to contain 2, 3 or 5 units per strip. There is a designation strip to match each length. One strip may contain any combination of devices, and the strips may be banked together to an unlimited degree. All of the devices are for service on voltages up to 220 volts. Each strip is mounted with two screws directly to machines, panels, etc.—*H. R. Kirkland Co., Morristown, N. J.*

Check these points of Cochrane's

"FRICTION-FREE" Electrical Transmission



In a measuring instrument high accuracy is achieved (1) by eliminating friction as far as possible (2) by applying ample power to overcome *inherent* friction.

In the Cochrane "Friction-Free" Electric Flow Meter both requirements are met.

STARTS WITH "FRICTION-FREE" TRANSMITTER

In the transmitter of the Cochrane Meter there are no stuffing boxes, bearings, linkages or gears—just a free moving float positioning a core within the transmitter coils.

RELIEVES MEASURING CIRCUIT OF ALL WORK

In the receiver of the Cochrane Meter high power from an external source overcomes the frictional load of pen, indicator and integrator, relieving the float and measuring circuit of all work.

ENDS WITH HIGH AND EQUAL POWER THROUGHOUT ENTIRE SCALE

The Cochrane Electric Flow Meter employs the NULL method of measurement, universally recognized as the most accurate means of measuring a force or quantity. By it, the float merely acts as a pilot, through a sensitive galvanometer, for an external source of power achieving high and equal power throughout the entire scale.

Because of this, Cochrane accuracy is a certainty, and can be guaranteed within exact limits at varying loads.

AND THIS GUARANTEE

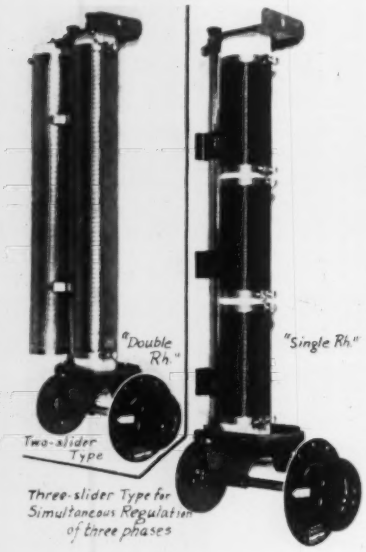
Within ½% of absolute accuracy on full load.
Within ¾% when operated at 75% of full load.
Within 1% when operated between 0 and full load on daily runs averaging 45% of full load.

COCHRANE CORPORATION
3120 N. 17th ST. • PHILADELPHIA, PA.

COCHRANE
FLOW METERS

Rotary-drive Rheostats for Switchboard Mounting

Several new designs, all for switchboard mounting, are announced of the lubricated-contact rheostats (full description of basic features: *Instruments*, Dec. 1939, page 316).



Angle of rotation of new rotary drive is 330°. Pointer indicates position of contact brush which is actuated by steel-cable system entirely free from back-lash. Illustration conveys idea of possibilities of combining sections in series, in parallel, etc., more than fifty styles being available. It may be noted that dividing the sliding path into two halves (left) permits using a small driving wheel taking no more space than width of rheostat.—*Rex Rheostat Co., 37 W. 20th St., New York City.*

Circuit-calculating Device for Attenuator Design

The "McProud Padget" is a slide-rule-like device for determining the resistors required for attenuators without resorting to extended calculations. Additional information is provided useful to the audio engineer, experimenter, or radio amateur. Resistor values are shown for pads of various configurations in 500 ohm circuits. For other line impedances, Z1, multiply all values shown by Z1/500. In the case of the bridged "T" pad, the 500-ohm resistances must be replaced with resistances equal to Z1. For unsymmetrical pads between impedances Z1 and Z2, not shown on the reverse side, the values P1 and P2 and the formulae may be used to calculate the proper resistances for R7, R8, and R9. K is the voltage ratio corresponding to the loss in decibels. "Grid Pot" shows values to be used in the grid circuit of a vacuum tube. On the reverse side, values are given for unsymmetrical pads between differing impedances. Power in watts applies to zero level of 0.006 watts. Volts across 500 ohms enables any rectifier-type AC voltmeter to be used as a power level indicator. For measuring distortion, or harmonic content, a common method is to adjust the output of the amplifier to the desired level with a constant frequency; insert a high pass filter; and measure amplification necessary, N db, to bring output up to the level obtained before insertion of filter. With the slide at a value corresponding to N db, read the distortion directly in percentage in the opening marked "Harmonic Content." For values of N greater than shown on the slide, subtract 20 db from N and divide the distortion shown by 10.—*Norman B. Neely, 5334 Hollywood Blvd., Hollywood, Calif.*

PORTABLE
WHEATSTONE BRIDGE

A high grade instrument for measuring resistances from a fraction of an ohm to 10 megohms. Contains a 4-dial rheostat, ratio dial, galvanometer and battery, all enclosed in a substantial walnut case. Nine coils per dial. Accuracy .1%. Built to endure.

Cat. No. 1050—Portable Wheatstone Bridge with Murray and Varley Loops...$110.00

Cat. No. 1052—Portable Wheatstone Bridge without Murray and Varley Loops..$90.00

Send for Bulletin No. 105

RUBICON COMPANY
Electrical Instrument Makers
29 North 6th St. Philadelphia, Pa.

"MEGGER"
INSULATION TESTERS

HAND GENERATORS UP TO 5000 VOLTS D.C.
RANGES UP TO 20,000 MEGOHMS

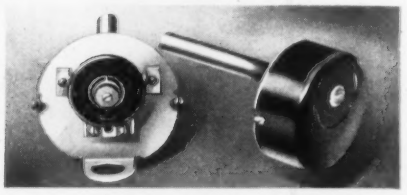
Designed for maximum convenience, portability and ruggedness for testing insulation resistance of all types of electrical equipment. A comprehensive assortment of types and ratings is described and illustrated in our Catalog 1550-I. Write for a copy.

Illustration shows our "Super-Meg" Insulation Tester being used by a "Hartford" insurance engineer.

JAMES G. BIDDLE CO.
Electrical Instruments
1211-13 Arch Street Philadelphia, Pa.

Air Thermoswitch

New Thermoswitch illustrated comprises, basically, a Fenwal Cartridge Thermoswitch (see *Instruments*, July 1938, page 176 for initial announcement and diagram) to



which has been attached a junction box, thereby providing facility for attaching BX cable or conduit to a terminal block within a protective cover. It is impossible on the Cartridge Thermoswitch to make use of any kind of protective cable over the lead wires or to incorporate a graduated dial and knob; Air Thermoswitch provides ready means of using both. Field of application has been widened; there is added the entire field of ventilation and air-conditioning. New Air Thermoswitches are catalogued as Regular (R) when the contacts open on an increase in temperature; Inverse (I) when the contacts open on a decrease of temperature. Adjustment is made by removing cover and turning metal knob. Standard, adjustment change 125°F. per full turn of knob; other temperature adjustments can be furnished. The adjustable operating range is—50° to 400°F. Contact rating, 10 amperes 115 volts; 5 amperes 230 volts a.c. ¾ hp—1ph 115-230 volts a.c.—*Fenwal Inc., Ashland, Mass.*

Outdoor-temperature-compensated Thermostat System

Chief use of new "Remote Bulb Econostat" is to regulate the heating system in apartment and office buildings, hotels, factories, etc. Intended for those installations

which cannot be satisfactorily controlled from a single thermostat, it regulates the heating system of the building directly from the outdoor temperature by supplying the heat at intervals. It maintains the desired indoor temperature by varying the "heat on" periods in accordance with outdoor temperature changes. Thus, the heat supplied to the building is in proportion to the heat loss from the building and is not dependent upon the temperature in any particular room. The "Econostat" is readily installed in either new or existing buildings, and will control any type of heating system whether fired by a gas or oil burner, stoker, or central station steam.—*Barber-Colman Co., Rockford, Ill.*

Industrial Pyrometry

Fourth instalment of new and completely revised edition of "Temperature Measurement and Control." We regret that circumstances beyond our control prevented fulfilling the promise made in this space last month: "The subject of pyrometry will be concluded in the December instalment." Two other chapters on pyrometry will follow. Some developments to be described therein are so recent that details are not available as we go to press.

By M. F. BEHAR

CHAPTER XI
VISUAL OPTICAL PYROMETRY

1. Modern Divisions of Optical Pyrometry.

Originally, optics was the science of light—of visible light. Since 1800, discoveries gradually revealed new regions of the spectrum of radiant energy—on both sides of the visible spectrum. Instrumental eyes were invented, capable of seeing farther and farther into the infrared; farther and farther into the ultraviolet. Some of these instrumental eyes can respond to waves a thousand times longer than red-light waves; others can respond to waves a million times shorter than violet-light waves. Even instruments utilizing the wave nature of electrons have become so common that recent years have witnessed the publication of books on electron optics. Optical pyrometry has benefited, of course, from these discoveries, so that it no longer is limited to methods employing the human eye. Whence the need of new names.

Where to find the new names? Not in dictionaries and encyclopædias: their compilers have not caught up because they wait for scientific authorities to advise them. But so rapid have been the advances in industrial "optical" pyrometry that the scientific societies and institutions which represent the highest authorities on this branch of physical science have not yet decided how to christen the new babies.

Some of these babies, by the way, are so far beyond infancy that they are on the payrolls of various high-temperature industries—under trade names given them by their manufacturers. What shall we (you, reader, and the present writer) call them in order that we may take up in the most convenient order (most convenient to us both) the numerous ramifications of modern industrial optical pyrometry?

Let's not be hasty. Let's not call them all "photoelectric." That would only complicate matters, as will be brought out later.

Here's a lucky circumstance: the word *Visual* still refers to the human eye; and there's little chance that it will ever be applied to the new babies. So let us apply it to all of the "old" types of optical pyrometers—and also to all future types of optical pyrometers depending on the human eye. This makes a convenient starting point. We can take up the Visual Optical pyrometers in this chapter and, in the next chapter, the new babies which are still unnamed. But now it becomes easy to name them: in the first place they are optical pyrometers (not total-radiation). In the second place they are non-visual; in other words they measure automatically; in one word they are autometric.

Hold on! Don't skip to the next chapter, no matter how fond you are of automatic methods, for the visual methods still hold the place of honor in optical pyrometry—and probably will hold it until 1950 or 1960 . . . perhaps for another century.

The fact is that the area of optical pyrometry became an athletic arena when the autometric instruments entered the various competitive events. Not only did the visuals improve their performance as a team but they split up into a number of teams competing with one another and setting new records for accuracy and general usefulness. At this writing (1940) there are more classes, types and varieties of visual optical pyrometers on the industrial market than there were of all pyrometers before the First World War (when the basic laws of optical pyrometry had already been formulated long enough for inventors to devise ten times as many different instruments as were available then).

Also, there is more *to* visual optical pyrometry than there was as recently as the nineteen-twenties when new types and varieties appeared at a greater rate than before or since. Thus, a comprehensive treatment of all classes and types would be a lengthy undertaking—which will not be attempted here; but a comprehensive treatment of all major subjects and of a selection of minor topics would fill a lengthy book—which could only be produced with the aid of financial backing from a wealthy institution, government department or individual. The only fairly exhaustive treatment of visual optical pyrometry (not a word about photocells except in the Introduction which explains that they "pertain to photometry, not pyrometry") is the famous *Traité de Pyrométrie Optique* by Gustave Ribaud, Director of the Pyrometric Laboratory of the Baron Edmond de Rothschild Foundation. This volume of nearly five hundred pages has about as many words as Gone With the Wind. It represents ten years of work by a staff of scientists and research assistants endowed by a French millionaire who in 1919 built a laboratory which he hoped would give his native land pyrometric research facilities on a par with those of the Bureau of Standards in Washington or of the Reichsanstalt in Berlin. Well, this *Traité de Pyrométrie Optique* has about twice as many bibliographical references as it has pages—and the papers referred to would overflow the proverbial five-foot shelf. Moreover, Ribaud's book is dated 1931 and is largely devoted to what might today be called "classical" visual optical pyrometry. A collection of the literature on *all* branches of visual optical pyrometry up to 1940 would probably overflow *two* five-foot book-shelves.

2. How to Grasp the Subject Without Knowing Mathematics.

To mention that the literature would overflow a ten-foot shelf isn't telling the whole story: We must add that it is printed in more than nine languages (Dutch, Japanese, Norwegian and other foreign workers made contributions since 1930). We must add also that most of it is mathematical.

No living man has read all these works. Talented men (mostly women, rather) who understand the languages and the mathematics, are employed as technical librarians and are kept busy reporting on other subjects. There's little likelihood of a book like Ribaud's ever coming out again, even if another benefactor like the Baron de Rothschild were to donate his fortune.

Nobody knows all about visual optical pyrometry. Even the greatest of the scientists are specialists.

Cheer up! It is precisely *because* of this huge accumulation of scientific data, including super-high mathematics, that the "average" industrial pyrometrist, who is not a mathematician, has at his disposal today a choice of reliable instruments, and a wealth of reference tables (some of them supplied by instrument manufacturers), which make it possible for him to measure high temperatures with the greatest of ease.

And with the highest accuracy?

In general, yes. The answer depends, however, on numerous factors: The instrument must be suited to the particular class of "body" or "surface" as will be explained later; the instrument must be clean and in good adjustment at the time of measurement; the observer must use it correctly; and finally the conditions must be right. This last proviso simply means the absence of sources of error—but as a rule the user will have learned to watch out for them: In other words, routine industrial measurements can be made with as fine a degree of accuracy as is obtained in any other branch of industrial instrumentation.

Routine measurements on *known* sources, with carefully-maintained instruments—such is the secret of the consist-

ently accurate results one hears bragged about at engineering conventions and other gatherings of technicians from various high-temperature industries. Moreover, after attending such meetings for some fifteen years, one must come to the conclusion that not only were the applications standardized, not only were the conditions uniform from day to day, but the applications and conditions were always such as to permit the use of the most highly perfected type of visual optical pyrometer, namely, the disappearing-filament monochromatic-light type. *That*, gentlemen, is not Pyrometry with a capital P.

To call it pure luck, however, would not be right, either. Nevertheless, the element of luck plays a part in modern industrial pyrometry, because the exact values of emittances and other conditions can never be foretold when a new application arises. The element of luck plays a part also whenever any instrument is purchased for taking the temperatures of several different sources. This is particularly true when a general-purpose instrument is purchased—no matter what its type. Therefore, the user of *any* optical pyrometer *should*, and the user of a general-purpose optical pyrometer *must*, have some knowledge of the science which he applies.

This science can be boiled down into several mathematical formulas. Only a mathematical physicist would find them sufficient mental equipment to start with. You, the reader for whom this book is meant, are not a mathematical physicist.

As promised a few paragraphs back, however, you need not have had mathematical training to become a first rate pyrometrist.

Visual optical pyrometry is the measurement of temperature by eye. That's what is was centuries ago before pyrometers were invented; that's what it is today. Our pyrometers help our eyes, so that we can measure within a few degrees whereas our forefathers did not even know the difference between heat and degree of heat. But the unimpachable evidence of old sword blades and other results of successful temperature control by eye proves that our forefathers could in some cases reproduce temperatures within 20 or 50 degrees.

Only the most skilled men could reproduce processing temperatures by eye. They had to have the gift—just as only a Michelangelo could at a moment's notice take a piece of chalk and draw a nearly-perfect circle upon a wall. In short, they were artists.

The art began to be a science with the gradual development of the Scale of Temperature, as narrated in Chapter I. A skilled ironsmith could connect his memory scale of color temperatures and brightness temperatures with the numerical scale of science and, therefore, when he wrote to a brother ironsmith that a certain process should be carried on at "3200 degrees on Fahrenheit's scale," this second worker would know how "white" and "bright" to run his furnace. The closeness of that knowledge would amaze many of today's youngsters who never came in personal contact with these old-time artisans.

The scientific explanation is already known to the reader: The brightness of an incandescent body varies from 15 to 25 times as fast as its absolute temperature, depending on the material and surface of the body, on the temperature range at which the process is carried on, etc. Therefore, an error of estimation which would be called huge when one estimates the weight of a package, or the speed of a runner, or the length of a bar, would become a relatively small error in terms of temperature.

An important relation—that between color and temperature—contributed to making a science out of the old art. Dull red, cherry red, orange, straw, etc., began to have quantitative meanings even when the instrument was the unaided eye. The scientific reason has been made apparent in Section 2 of the preceding chapter, where the main facts about the blackbody laws were set forth. It is obvious that the color change is most pronounced at temperatures between 1000 and 3000 degrees Fahrenheit: from the first visible red to the temperatures at which most bodies begin to appear white.

The next step in the reduction of the art to a science is to take advantage of the simultaneous color shift and brightness increase—by merely using a piece of colored glass. This is an important step forward because it ties in *radiant* energy and *luminous* energy. Without such a tie-up, there could be no such thing as visual optical pyrometry.

Another great step forward was the idea of *matching* brightnesses—whether in the sense of "white" or red—instead of estimating them in absolute terms. The accuracy could be enormously increased, particularly if the observer could look through some sort of a telescope in which the field of view was divided so that he would see the image of the unknown source in one half and the image of a standard source in the other half. That kind of an instrument is known as a visual-match photometer. Even an untrained human eye can match the two halves of the field of view to one percent, whereas brightness memory and color memory —even of an artist—are erratic.

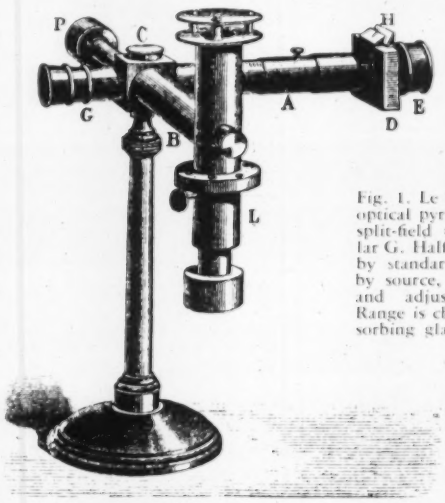


Fig. 1. Le Châtelier's photometric optical pyrometer. Observer views split-field through red-glass ocular G. Half of field is illuminated by standard lamp L; other half by source, through object-lens E and adjustable diaphragm D. Range is changed by inserting absorbing glass at E. *(Ribaud)*

It is interesting to note that in 1863, twenty-one years before the Stefan-Boltzmann law, thirty-three years before the Wien laws, Becquerel propounded the general principles of monochromatic pyrometry—matching the intensity of red light from the furnace, or forging, or molten-metal stream, against the intensity of red light from a standard source. The obstacle was that there was, at that time, not a single reliable method of measuring high temperatures in order to proivde the required standard sources.

(Extrapolate by a wedge method? Of course the scientists tried that, back in the seventies, when the science of photometry was well on its way, but the errors were actually greater than those of the unaided eye of an experienced melter. The wedge could not be perfected as a correctly-graduated temperature-measuring device until the concepts of the graybody and of the gray medium were fixed—and these concepts could not be imagined until the laws of the blackbody and their relation to the normal human eye were thoroughly worked out early in the twentieth century.)

So it was not until the development of rare-metal thermocouples that standard sources could be made available for realizing the idea conceived 'way back in 1863. It was around 1890 that Le Châtelier perfected his platinum and platinum-rhodium couple; and he lost no time in designing the first practical optical pyrometer (Fig. 1). This was in 1892, four years before Wien formulated his laws. Therefore, at that time, no one knew exactly how fast the intensity of red light increased with increasing temperature.

Le Châtelier, however, made it possible to "calibrate" his supposedly "monochromatic" optical pyrometer in terms of supposedly "true" temperatures of supposedly "blackbody" sources up to near the softening point of his platinum and alloy wires—which was high enough for nearly all metallurgical industry requirements. The visual "emissivity" properties of actual materials at high temperatures began to be studied on a "quantitative" basis. "Correction" tables began to be distributed to industrial users of Le Châtelier's instruments.

That was the beginning of optical pyrometry. It could have been gradually refined by cut-and-try methods, but there were fundamental obstacles to be overcome. Some of these obstacles are indicated by the words in quotation marks in the foregoing paragraph. They could not be overcome until—

—until (1) the portrait of blackbody radiation (Sec. 2 of Chapter X) became accurately known,

—until (2) this set of exact figures was tied up to another body of exact data on Light and Visibility,

—until (3) the transmission properties of various media became exactly known,

—and until (4) the emission properties of various materials and surfaces were named, listed and charted.

This last-mentioned work (see Sec. 3, Ch. X) is still under way: it never will be finished.

Let us return to the beginnings of visual optical pyrometry and mention another invention. Actually, it was born at the turn of the century—four years after Wien announced his laws, but its development owes as much to the four "untils" mentioned above as does the development of the Le Châtelier class, so we may consider that both classes were conceived before the formulation of the radiation laws.

When electric lamps had become fairly well standardized, Holborn and Kurlbaum in Germany, and Morse in the United States, simultaneously and independently conceived the idea of doing away with the optical-instrument parts of a divided-field photometer, by simply looking through a red glass

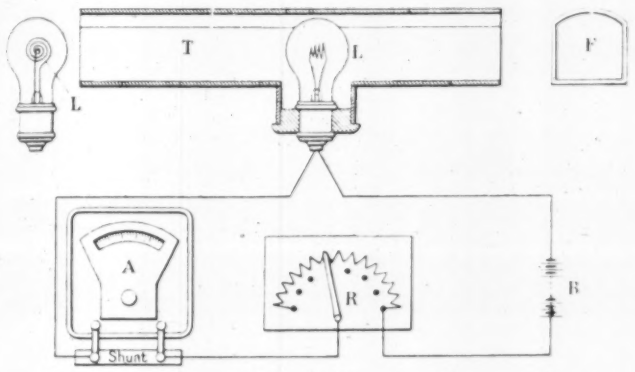


Fig. 2. Schematic diagram of Morse's disappearing filament optical pyrometer. *(Ribaud)*

close to the eye, and through a carbon-filament lamp, *at* the furnace or other source. The filament is seen as a line crossing the furnace peephole or the ingot, or the molten-metal stream. Fig. 2 shows that simple idea—the basic principle of the majority of visual pyrometers in use today. This made possible a different matching method: Le Châtelier's pyrometer included a standard lamp (a delicate scientific device in 1892) and the photometric match was made by cutting down the luminous flux from the source by means of a diaphragm (*D* in Fig. 1) to which the temperature scale was attached. In the disappearing-filament pyrometer, this could have been done (and it was done in later designs) but from the start the German and American inventors decided to vary the lamp current (by rheostat *R*, Fig. 2) until the filament "disappeared" against the background of the source, and then reading the temperature on ammeter *A*.

Differences in matching methods as well as in basic ideas led to modified types and later to refinements of all designs.

At this point it may be well to illustrate the disappearing-filament idea. Fig. 3 does not show photographs taken through Morse's original model: it shows three photographs taken through the Leeds & Northrup Morse type instrument.*

There is another type of monochromatic visual pyrometers: the polarizing type, so called because the brightness of the image of the source is cut down by rotating a Nicol prism until it matches the brightness of the image of a standard lamp.

*This instrument has been superseded by a new type, described in Section 4, in which a straight filament crosses the field of view. However, Fig. 3 remains an excellent pictoral presentation of the disappearing-filament idea.

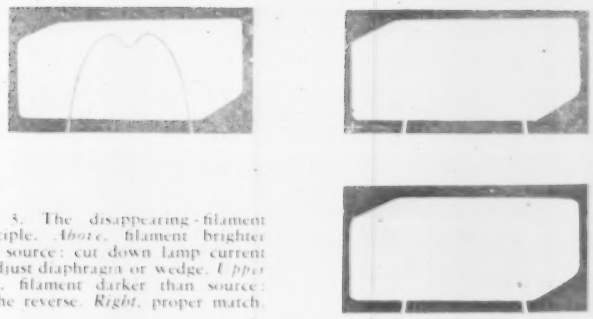


Fig. 3. The disappearing-filament principle. *Above*, filament brighter than source: cut down lamp current or adjust diaphragm or wedge. *Upper right*, filament darker than source: do the reverse. *Right*, proper match.

These and other types constitute the brightness-matching category. Only a few types have "survived" in this country in that they are favored by American pyrometrists.

Another broad category of visual pyrometers is represented by color pyrometers. It includes various classes, utilizing different principles of color temperature measurements. All of these principles, however, are themselves based on the blackbody radiation laws whereby not only the intensities of all frequencies are exactly known but also the *ratios* of intensities of any two frequencies such as blue and red, green and red, etc. If perfect colored glasses, gelatins, plastics, etc., were available, these instruments would become more popular, for their construction is generally simple and some of them are vest-pocket size. The color ratio is determined in various ways by moving the two filters (and sometimes a third "gray" filter) in relation to one another.

The "extinction" class belongs both in the "brightness" category and in the "color" category. One popular type comprises a glass or dyed gelatin screen which transmits more blue and red than the intervening colors of the visible spectrum. This screen is denser at one end than at the other. The observer slides it back and forth until he finds the spot (or region) where he barely sees the source. An even simpler type in the extinction-wedge class consists of a green wedge: the green is not spectrally pure, so that a red-hot source can be seen through the clearer end, a yellow-hot source through the middle, and only a dazzling-white source through the denser end. The simplest type is a "gray" or neutral or achromatic wedge—or rather an approximation of this irrealizable ideal material.

The variable-color-ratio pyrometers and the fixed-color-ratio extinction-wedge pyrometers are sometimes claimed to have a theoretical advantage over brightness-matching pyrometers, namely that corrections for the emittances of actual surfaces are theoretically negligible. This is not true.

It may be seen that visual pyrometers are difficult to classify. The following table is incomplete and perhaps scientifically faulty but it has been constructed to serve as a guide to the types in use.

Division	*Class*	*Type*
Brightness	Photometer 1. Equality field 2. Contrast field 3. Flicker Etc. photometrically	Variable distance Variable diaphragm Absorbing wedge Rotating sector Rotating polarizer
	Disappearing-filament 1. Ammeter 2. Potentiometer Etc. electrically	Variable current Variable diaphragm Absorbing wedge Rotating sector
Color	Extinction of total luminous flux	"Gray" wedge
	Extinction of most-visible color	"Green" wedge
	Color ratio	Two colored wedges do. + absorbing wedge

3. Temperature Measurement Essentials.

The aim of the foregoing section was to introduce, in non-technical and non-mathematical terms, all main subjects and a few subordinate topics. There will now be given a few essentials and a few suggestions for collateral reading.

Of prime importance are the *blackbody laws*. The ultimate reference standard against which precision visual pyrometers are calibrated is not a material body but *radiant energy* emitted through a small orifice from a uniform-temperature enclosure. Section 2 of the preceding chapter should therefore be considered as forming an essential part of this chapter.

For precision work, a calibrating department should if possible be equipped with a reliable blackbody source. Several forms are on the market. Perhaps the best form within the budget of a fairly large plant where optical pyrometry is extremely important is that described in *Bu. of Stds. Research Paper 325* (1931) by Wensel and associates. Fig. 4 is a diagram of its essentials—the induction-furnace windings not being shown.

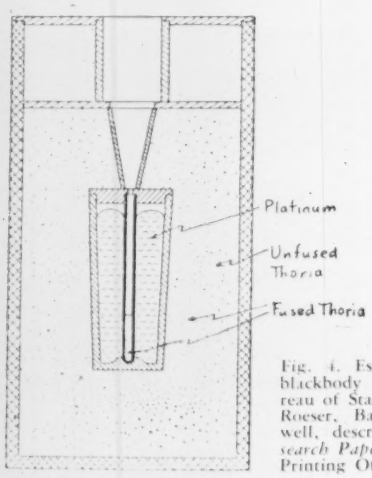


Fig. 4. Essential portion of blackbody developed at Bureau of Standards by Wensel, Roeser, Barbrow and Caldwell, described in their *Research Paper No. 253* (Gov't Printing Office, 5 cents).

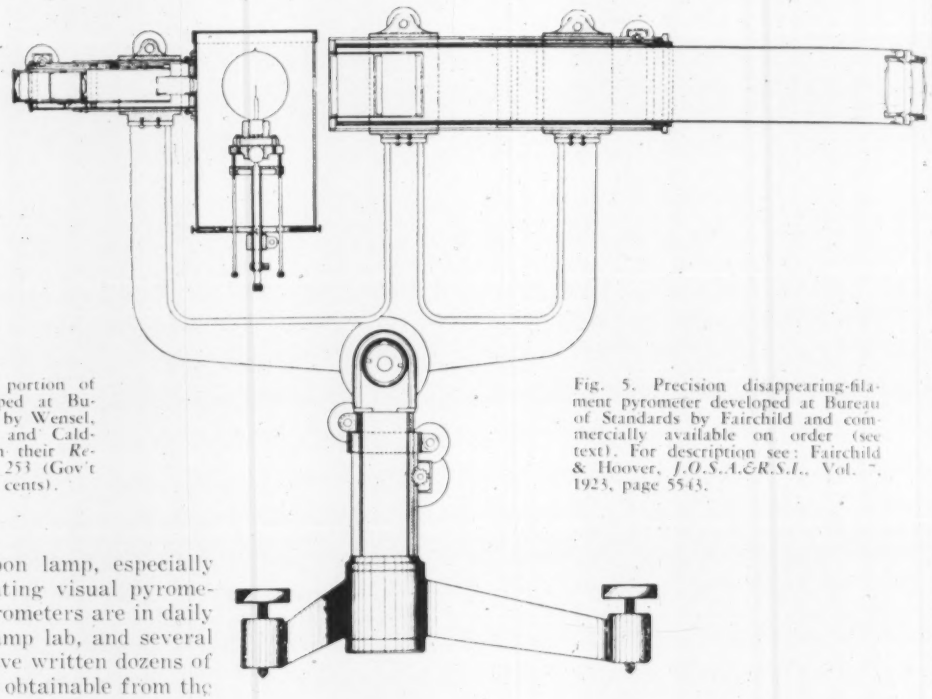


Fig. 5. Precision disappearing-filament pyrometer developed at Bureau of Standards by Fairchild and commercially available on order (see text). For description see: Fairchild & Hoover, *J.O.S.A.&R.S.I.*, Vol. 7, 1923, page 5543.

At least one standard tungsten-ribbon lamp, especially designed and manufactured for calibrating visual pyrometers, is the absolute minimum where pyrometers are in daily use. Forsythe and Worthing at GE's lamp lab, and several workers at the Bureau of Standards, have written dozens of papers on this subject. These lamps are obtainable from the Bureau.

A precision optical pyrometer, in spite of its being delicate (merely transportable rather than portable) finds many uses not only in the calibrating room but wherever it can be set up without danger of injury. Fig. 5 is a sectional view of Fairchild's design as used at the National Bureau of Standards since about 1918. A number have been made for various industries by Bureau of Standards mechanics (working spare time) and by the American Instrument Co. The gap at the right of the comparison-lamp housing in Fig. 5 is for a rotating sector—one assigned to the pyrometer or one borrowed from a photometer bench whenever necessary. For measuring the lamp current, a direct-deflection ammeter would not be accurate enough, so a potentiometer is considered an essential part of a precision visual pyrometer.

Even a brief discussion of standards must not fail to mention the oft-forgotten "standard" inside most types of industrial visual pyrometers: the comparison lamp. Recent years have witnessed improvements in these lamps, the newer "box" forms being designed and constructed especially for this service, with inclined flat windows as well as with numerous other "features" all aimed at enhancing the accuracy of *temperature* measurements. With modern lamps this accuracy now depends on the related instrument factors. Thus, pyrometers of the current-measuring types can be "accurate to one degree" if the current can be measured to 0.1%.

Optical pyrometry shares with radiation pyrometry the requirement that the source must emit a continuous spectrum; it differs from radiation pyrometry in that the receiver is "selective." The criterion for applying the adjective "selective" is that the receiver does not respond according to the Stefan-Boltzmann fourth-power law. In general the power is higher than the fourth. It never is constant except in the hypothetical case of a receiver automatically selecting the peak-energy wave-length interval: shifting toward the higher frequencies as the temperature rises (and vice versa) in which case the power would be the fifth. In all other cases, where the center of gravity of the receiver's curve remains fixed—except for the slight temperature coefficients of colored glasses, etc.—*the power varies.* Inspection of the distribution curve discloses at a glance that the most rapid rise is in the region at the left of the peak-energy wave-length. But this peak-energy wave-length is inversely proportional to the absolute temperature. It follows that the response of any highly selective receiver, no matter where its center of gravity is located, will vary over the range of temperatures which it is designed to measure. Thus a nearly-monochromatic receiver with its center of gravity at 0.65μ (red light) responds most rapidly to temperatures in the industrial range; around 8000°F. its response is the fifth power; at higher temperatures its response becomes less than the fifth power.

Fig. 6 shows the basis of monchromatic optical pyrometry—whether visual or autometric: the reason why a monochromatic receiver can be calibrated in degrees of blackbody temperature.

A receiver may consist of a slightly-selective or even blackbody receiver-proper (the sensitive element) plus a more-or-less monochromatic screen or other selector. Thus the combination of a blackened thermopile receiver and a monochromator is the most selective "optical pyrometer"—though its use is in spectrometry rather than in pyrometry.

Only the monochromator (or any spectroscope arranged to provide the desired spectral purity) makes possible ideally sharp selection. The great majority of receivers and of filters are characterized by absorption or transmission *curves*, with reference to radiant energy.

The *human eye* is a selective receiver of radiant energy. It responds to light. Light is defined by the I.E.S. as "radiant energy evaluated according to its capacity to produce visual sensation." Exact quantitative terms can only be given for what is known as the Normal Observer—an international standard based on thousands of experiments—because

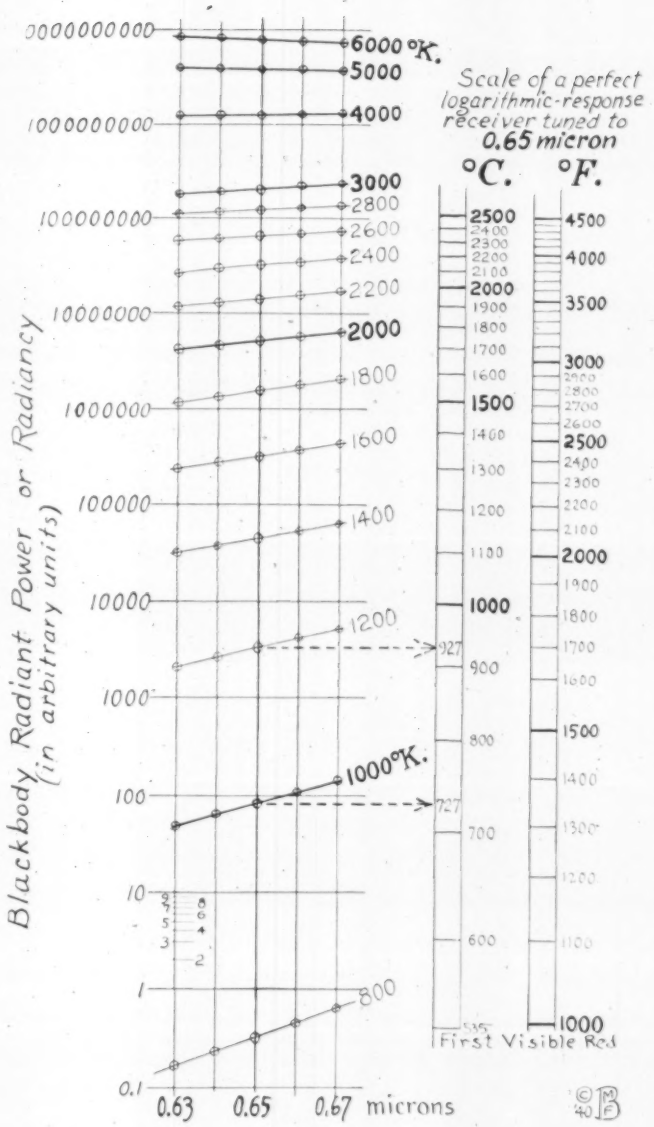


Fig. 6. The foundation of monochromatic optical pyrometry.

individuals differ widely, even without considering color-blindness and other abnormalities, and because the eye is not an ordinary physical receiver but a psycho-physical receiver whose constants are affected by subjective variations —fatigue, experience, attention, etc.—and by organic disturbances in remote parts of the body.

The eye responds, roughly speaking, to one octave of radiation: 0.4μ to 0.8μ. These are the easily-remembered round numbers. Many individual eyes respond to 0.3μ (which is "ultra-violet" for others). Many individual eyes respond to 1μ (which is "infra-red" for others). In such cases the visual sensation is obtained by using an extremely powerful light source in the apparatus: only a small part of the radiant energy is seen as light; the other 99— percent produces discomfort or injury if the experiment is unduly prolonged. Between 0.5 and 0.6μ lies the region of maximum sensitivity for all eyes; most persons have no difficulty in seeing the 0.33μ violet and the 0.77μ red at comfortable intensities. The wave-lengths which produce the various colors most unmistakably are as follows:

Violet	0.41	Yellow	0.58
Blue	0.47	Orange	0.60
Green	0.52	Red	0.65

The visibility curve at daylight intensities bears a striking—and natural!—resemblance to the sun's energy distribution at the surface of the earth, as filtered by the atmosphere. This Normal Observer curve is shown in Fig. 7. It is known also as the visibility function, the luminosity curve, etc.

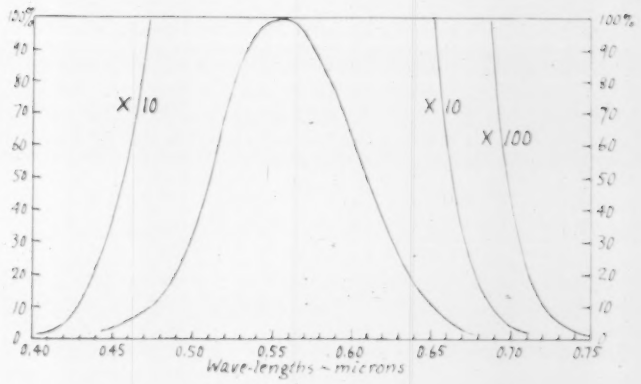


Fig. 7. The visibility curve.

At high intensities the maximum of the curve lies more in the yellow; at low intensities it lies in the green, between 0.50 and 0.52μ. Therefore, the idea of using 0.70 or even 0.72μ glasses for pyrometry, while attractive from the standpoint of extending ranges and obtaining faster response at low temperatures, would result in eye-strain and poor matching. Besides, the usual 0.65μ glasses are so designated because of their center of gravity with reference to *light*: most of them transmit twice as much *energy* at 0.75μ than they do at 0.65μ.

This brings us to the relations between radiant energy curves and light curves. The visibility curve is the starting point of calculations, definitions and values. Thus, by mul-

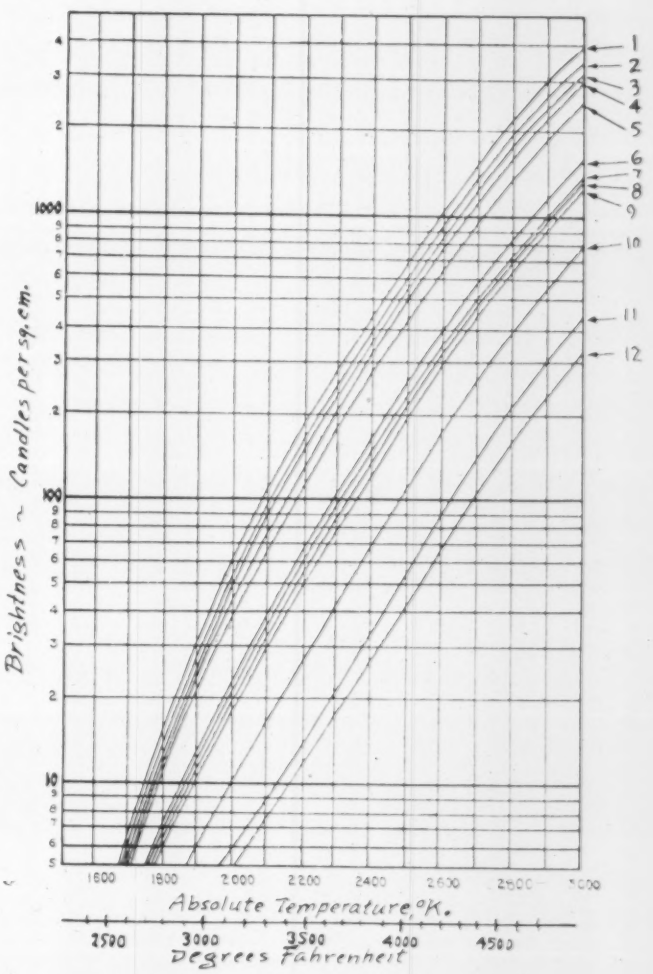


Fig. 8. Relation of brightness to temperature for the blackbody and various materials. Values are accurate for the blackbody; they are increasingly rough as the "emissivities" decrease, beside having been extrapolated beyond some melting-points. 1. Blackbody. 2. Lampblack or carbonized nickel. 3. Iron oxide (Fe_2O_3). 4. Carbon. 5. Carbon filament. 6. Tantalum. 7. Tungsten. 8. Molybdenum. 9. Platinum. 10. Copper. 11. Aluminum oxide (Al_2O_3). 12. Magnesium oxide (MgO).

tiplying the ordinates of any blackbody curve of spectral *radiant* intensities by the corresponding visibilities, there is obtained the blackbody curve of spectral *luminous* intensities for the temperature of the blackbody. Obviously, the curve of a blackbody at room temperature, or at any temperature below the first visible red, cannot be translated into a luminous intensity curve. Obviously, too, the *brightness* (area under the luminous curve, corresponding to the

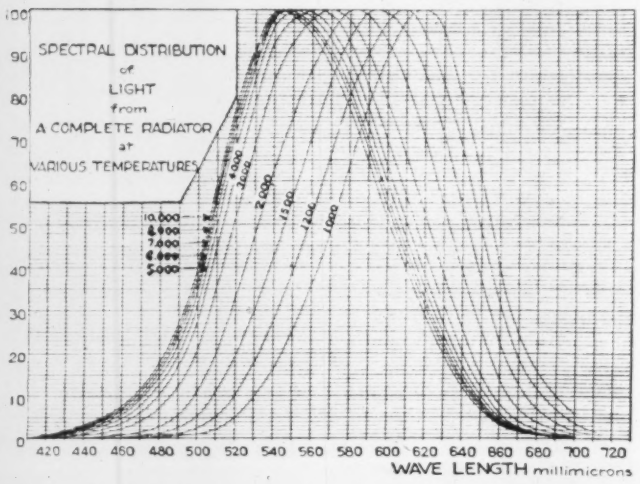


Fig. 9. These are luminosity, not radiant energy, distribution curves. *(Priest)*

radiancy of total radiation) increases as a higher power of the temperature than does the radiancy. See Fig. 8 (and compare it with Fig. 8 of the preceding chapter on Radiation Pyrometry.)

Another effect is that the luminosity curve shifts toward the shorter wave-lengths as does the energy curve, but always stays within the spectral limits of visibility. Fig. 9 is

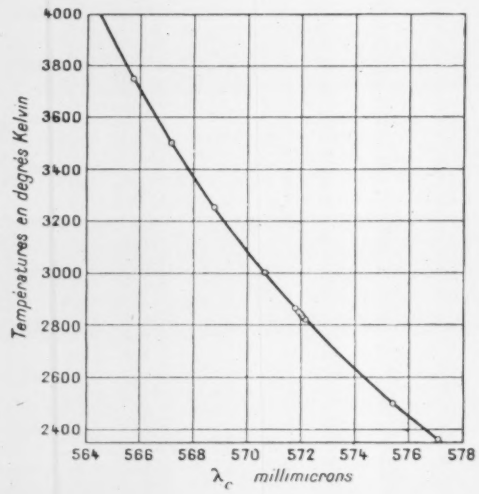


Fig. 10. Unlike that of the energy curve, the center of gravity of the luminosity curve does not pass into the ultraviolet, however high the source temperature. *(Ribaud)*

from the famous *Bu. of Stds. Sci. Paper 417* (1921) by Priest: it shows a series of the luminous curves for eleven temperatures, all plotted on different scales so that the peak luminosity is always "100."

The centers of gravity of blackbody luminosity curves shift toward the violet as shown in Fig. 10 (from Ribaud who plotted values computed by Priest).

Figs. 9 and 10 bring out the basis of "*color temperature*." The color temperature of a body is simply the temperature of a blackbody having the same color. In Forsythe's more precise terms, the color temperature of any non-blackbody is "the temperature at which it is necessary to operate a blackbody so that its radiation will match in integral co the source studied."

The *brightness temperature* of a non-blackbody, similar is the temperature of a blackbody having the same brigl ness *at some specified wave-length*.

Another interesting approach to the subject of the col of blackbody radiation began as far back as 1881 wh Crova first pointed out that there exists a wave-length the spectral energy curves of two sources, at which wav length (known as the Crova wave-length) the ratio of th two radiant intensities equals the ratio of the two tota luminosities. For many years this wave-length was believe to be a constant of the human eye, and by the beginning o this century the value of this supposed constant was give as 0.58μ.

Not until after 1910 did Ives, Nutting, Foote, and othe workers demonstrate that there is no such constant. How ever, the experiments led to the publication of various types of families of curves which in turn, when studied by numer ous pyrometrists throughout the world, aided in fixing the concepts involved. In the report of one famous series of experiments, Priest included a figure showing a family of curves of blackbody radiation pertaining to what was then

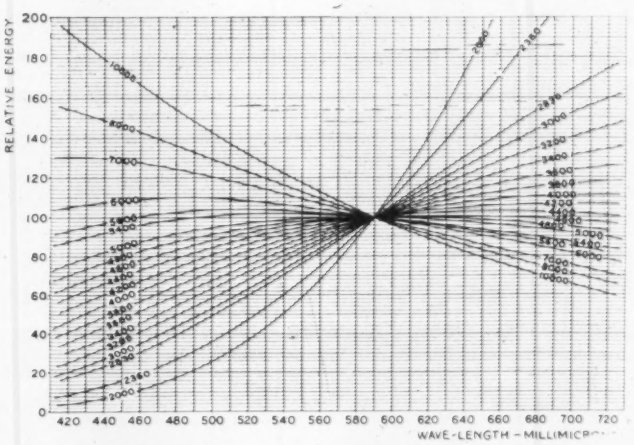


Fig. 11. Here again, energy curves—or portions thereof in the visible—all drawn to make the energy at 0.59 micron equal "100." *(Priest)*

known as the "yellow-blue transition temperature." In that diagram he had all spectral energy distribution curves plotted with the 0.59μ ordinate arbitrarily fixed at 100. In his later paper* he published the diagram here reproduced as Fig. 11. Note that the abcissa extend over the visible spectrum only: in visual pyrometry the entire portrait of radiation does not have to be depicted.

This type of diagram is frequently used for specifying the colors of illuminants. As a matter of interest, it may be mentioned that average noon sunlight at the latitude of Washington, which actually has an irregular distribution when narrow wave-length intervals are carefully measured, is closely approximated by the 5000°K. curve of Fig. 11; the average daylight at Washington (also an irregular curve actually) by the 6500°K. curve of Fig. 11; and the blue sky by the 10000°K. curve. We repeat, these are blackbody spectral *energy* distribution curves.

The chief value of Fig. 11, however, is that it brings out the scientific basis for bichromatic pyrometry. It is evident that for every blackbody temperature, there is a ratio of spectral radiant intensities in the red and in the blue, which ratio varies rapidly enough to make possible accurate temperature measurements without need of close measurements of the two radiant intensities—translated as the two *brightnesses*.

Now, when we examine the luminosity curve, Fig. 7, we note that the sensitivity of the human eye at 0.47μ is 10% of its maximum and also 10% at 0.65μ. Therefore, a pair of photometric devices, one with a 0.47μ blue glass and one

*J.O.S.A.&R.S.I., Vol. 7, 1923, page 1175.

ith a 0.65μ red glass, will constitute a pyrometer which oes not require measuring the two spectral brightnesses ut only their ratio. Ribaud, Forsythe and other workers ave worked out the mathematics of this bichromatic py- ometry when applied to non-blackbodies. Ribaud has shown hat there are certain relations which can be plotted as traight lines. This branch of visual pyrometry has a prom- sing future. Of the pyrometers now being manufactured, owever, it may be said that they only represent a begin- ning. Another beginning may be chronicled in a related ield, namely the measurement of color temperatures of illu- minants in amateur photography by means of "color tem- perature meters" which utilize the bichromatic ratio prin- ciple. The first of these to appear on the market is that made by the Eastman Kodak Co. It is described at the end of this chapter but we may quote here two paragraphs from the instruction book; applicable with even greater strength to the *pyrometers* belonging to this class of temperature-measuring instruments:

> In reading the instrument, it is always good practice to make a number of determinations, say, at least five, and take the average. With experience, it is possible to read the color temperature of studio lamps to an accuracy of less than fifty degrees.
>
> The use of the instrument presupposes normal color vision. *Color blind people will not be able to use the meter, and neither will those who have certain abnormalities in their color vision.* There is much difference in the color accommodation between different people and sometimes between the two eyes of the same person. [The makers of candid cameras are candid about the limitations of this *class* of temperature-measuring instruments!—MFB]

Visual Pyrometry of Non-blackbodies.—Graybodies. A graybody material is one whose emissivities are all less than unity but are all equal. There is no such material from the standpoint of total-radiation pyrometry. In monochromatic visual pyrometry, only one set of the spectral emissivities is of interest. When these vary but little with temperature they can be compiled in usable tables—and have been for some materials. In short, the "double infinity of factors" (Forsythe's apt phrase) which makes accurate radiation pyrometry so difficult in so many cases, though not theoretically reduced to a workable minimum, is practically reduced to perhaps three listings.

So much for any graybody material. An actual body made of that same material will not have the tabulated graybody properties unless its surface is clean and polished. Even so, it must not be inferred by the reader that all the emittance values at any wave-length will be uniform. Differences are frequently found. For example, the incandescent surface of the helical filament of an ordinary lamp, when viewed under a microscope through two or three colored filters (to obtain an extremely narrow wave-length interval: spectral purity) shows graduations from bright to dull, depending on the angles of emission—the azimuth angles and the altitude angles. Such a surface has passed through diamond dies, has been untouched by hand, and when fresh from the factory has not been oxidized or otherwise affected: it is mechanically uniform but nevertheless displays a variable relation of temperature to spectral luminous intensity. Therefore the published value of the "emissivity" (even the normal spectral emissivity) of any important material should not be assumed to hold true for all the emittance properties of an actual body made of that material.

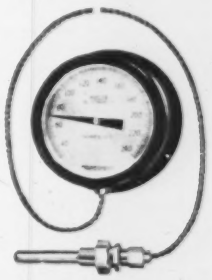
Actual non-blackbodies. Since the great influence of the character of actual surfaces is *visible*, the pyrometrist quickly acquires the habit of sighting certain kinds of spots or regions, and avoiding others, when taking reading on slabs, etc., whose surfaces are non-uniform. Experience thus gained then proves valuable when measuring temperatures of different materials having different non-uniform surfaces and consulting tables of "emissivities." It always is extremely important to make sure that the data apply to the particular kind of surface whose temperature is to be measured. At this writing (1940) correction charts subdivided into tables referring to specified surfaces have been published for only a few important materials; and they are far from complete. There are some useful bits of data, however, such as on molten-metal streams and other widespread in-

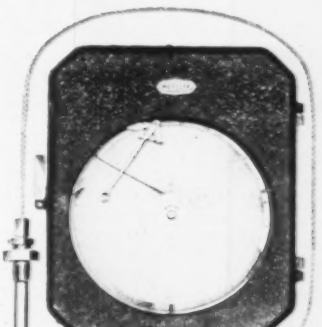
MOELLER

PRECISION GRADE INSTRUMENTS

MOELLER MERCURY THERMOMETERS are made with the Moeller Glass Red Reading Column making them easy to ready under varying light conditions, at a considerable distance and over a wide range.

MOELLER DIAL THERMOMETERS are made in various scale ranges up to 1000 F. or equivalent. Metal and Phenolite cases.





MOELLER RECORDING THERMOMETERS are likewise furnished in various ranges up to 1000 F. or equivalent. Round and square cases as preferred.

Also HYGROMETERS
RECORDING PSYCHROMETERS
BAROMETERS HYDROMETERS
MARINE INSTRUMENTS, ETC.

Write for catalog.

MOELLER INSTRUMENT COMPANY
132nd STREET and 89th AVENUE
RICHMOND HILL NEW YORK

Sales Representatives in Principal Cities

dustrial applications. At present the accuracy of visual pyrometry is spotty: extremely high where emittance corrections are known and correctly applied, unsatisfactory where guesswork is compelled for want of applicable specific data. What is needed is the compilation, for every important material, of a complete series of emittance *curves*—complete

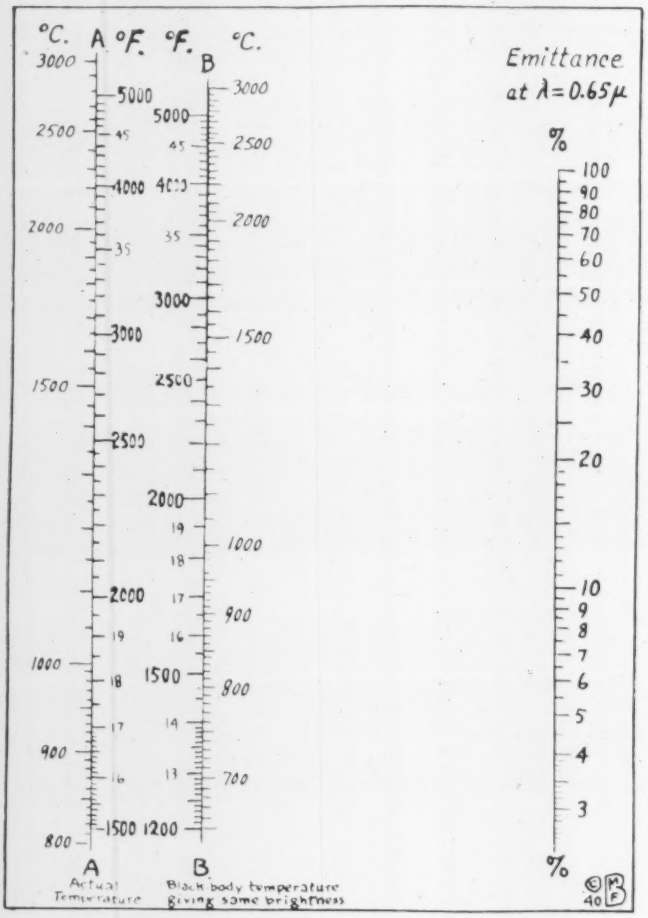


Fig. 12. Do not use this alignment chart unless you know your emittances.

except for unusual surfaces. Meanwhile, the serious pyrometrist should familiarize himself first of all with the terminology (Sec. 3 of Ch. X) as a first step in cultivating a critical attitude toward many *general* emissivity correction tables and charts . . . including for example Fig. 12 which was drawn by the writer of this negative advice!

Effects of Intervening Media. Visual pyrometry has a great advantage over total-radiation pyrometry in that the presence of intervening media between source and pyrometer is seen (an invisible medium cannot cut down the measured spectral brightness) and the seriousness of their effects readily estimated. Thus CO_2 and water vapor do not cause errors.

Transparent materials are gray media by reason of surface reflection. Thus a soap-bubble-thin sheet of glass or quartz has no color whatever, but it only transmits 92% of any wave-length in the visible; 8% is lost at the two surfaces. A visual pyrometer has a number of glass surfaces and therefore its initial factory calibration will remain constant so long as these surfaces are kept in their original condition. This seldom causes errors. Sighting a source through any solid medium, however, does make a difference, however clear the material and however small the thickness. An extremely useful correction chart has recently been constructed by Benford and is reproduced here (Fig. 13). The temperature scale across the bottom of the chart is, of course, the absolute scale, in degrees Kelvin, and the markings are the uncorrected degrees as indicated by the pyrometer. The curved lines may represent several factors such as (a) transmission factor of glass, (b) emittance of radiating surface, (c) combined effects of factors (a) and (b). Several examples were worked out by Benford to illustrate the various way in which his chart may be used:

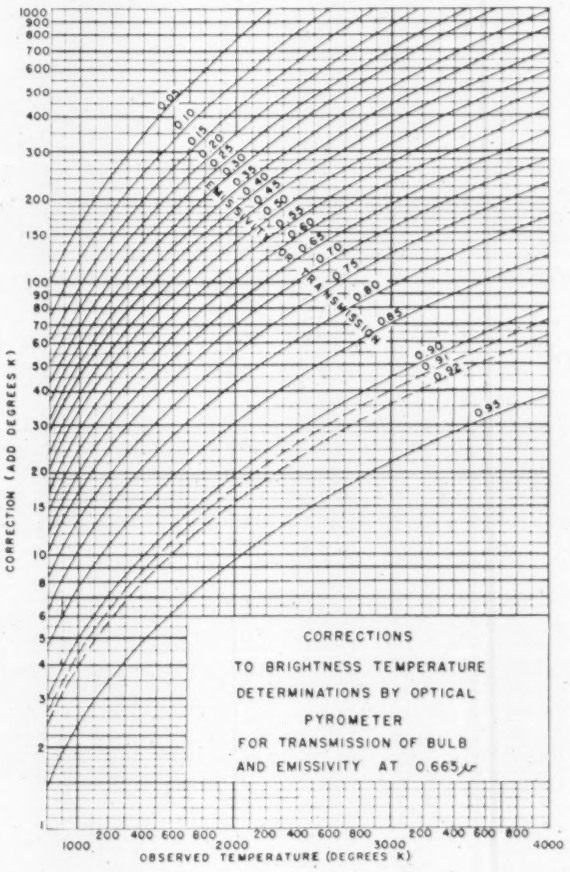


Fig. 13

Example 1. Bulb corrections are made as follows:

Observed brightness temperature	2800°K.
Bulb transmission (known)	0.91
Bulb correction (from chart)	35°
Corrected brightness temperature	2835°K.

Example 2. If the emissivity (at 0.665μ and at the test temperature) is known, the true temperature of the above radiator can be found as follows:

Brightness temperature (using observed temperature scale of chart)	2835°K.
Emissivity (known at 0.665μ)	0.60
Emissivity correction (from chart)	204°
True temperature	3039°K.

Example 3. From pyrometer readings on the surface of a radiator, and from readings on a cavity in the same radiator the emissivity is determined as follows:

Surface reading	2200°K.
Bulb transmission (known)	0.91
Bulb correction	22°
True brightness temperature	2222°K.
Cavity brightness (observed)	2550°K.
Bulb correction	29°
True cavity brightness temperature	2579°K.
Difference, cavity minus surface	357°K.
Ordinate at 2222° on temperature scale and abscissae at 357° on correction scale cross near curve marked 0.25 gives emissivity	0.26

Example 4. A filament observed through a clean section of bulb has an observed brightness temperature 45° higher than when observed through a section having a thin metallic coating. The transmission of the coated section can be found with the aid of the chart.

Reading through clear surface	1500°K.
Bulb transmission (known)	0.92
Bulb correction	9°
True brightness temperature	1509°K.
Reading through coated surface	1360°K.
Loss in coated section (1509–1360)	149°K.
Curve at 1360° ordinate, 149° abscissae	0.22
Bulb transmission	0.92
Deposit transmission (0.22/0.92)	0.24

*Frank Benford, Temperature Corrections in Optical Pyrometry. *Journal Optical Soc. of Am.*, Vol. 29, April 1939, pages 162-163.

4. Industrial Forms

Complete coverage of the makes is not intended in this section. Only a few examples are selected. The descriptions being designed to bring out technical features one by one when read consecutively, only the first in each type is adequate, the others purposely brief.

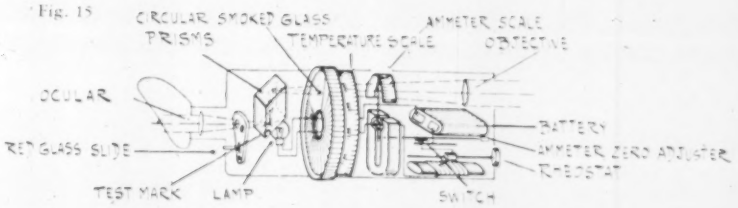
(a) Brightness-matching

CLASS I—PHOTOMETRIC

Combridge Instrument Co.'s Nicol Prism Type. This is a photometer in which monochromatic light from the object sighted is adjusted to equal intensity with a beam of similar light from an incandescent lamp: Light from the source enters the instrument through one aperture while through another enters light from the lamp. The two beams pass through an optical system whereby they are polarized in different planes, and rendered monochromatic; they then pass through a Nicol prism into the eyepiece. The field seen by the observer is divided into two semi-circles, illuminated by the source and the electric lamp respectively. The eyepiece, to which is attached the scale pointer, is rotated until the two semi-circles are equally illuminated, and the temperature is then read directly on the scale engraved on the large circular plate (which forms a convenient shield). The electric lamp is checked against standard amyl-acetate lamp supplied with each outfit, and its current standardized by altering the resistance accordingly. Double-scale instruments are provided with an absorbing screen, which is moved in front of the objective when using the higher range. Standard ranges for single-scale instruments are 700 to 1400°F. and 900 to 2000°C. For double-scale instruments, the same two and others up to 4000°C.

Fig. 14

Fig. 15



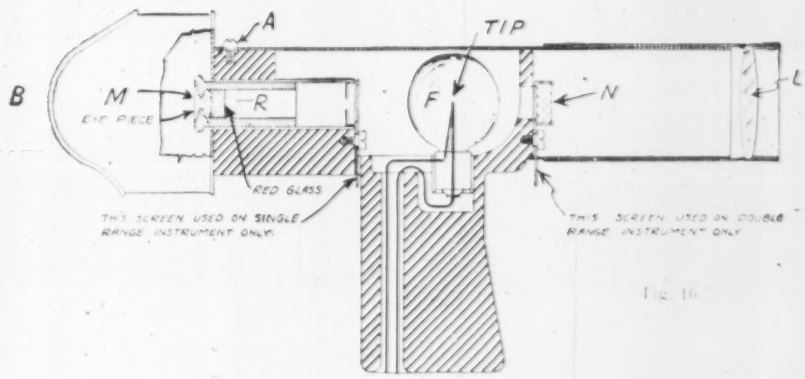


Fig. 16

"Pyro." (Pyrometer Instrument Co.). This is a German-made self-contained instrument (weight 3 lbs.) employing a photometric cube device whereby the *central* part of the field of view is illuminated by the lamp, and a circular wedge for attenuating the brightness of the source until the small inner circular part of the field and the large annular part of the field are brought to a match. The wedge is a circular one, made of clear glass with an emulsion of varying density on it. Lamp current is standardized by the rheostat and ammeter, used in conjunction with a "master lamp" inserted periodically in place of the working lamp, at which time the temperature scale is adjusted. Between standardizations, lamp current is then checked by pressing the ammeter contact button and adjusting the rheostat only. Other construction details are brought out in Fig. 15.

CLASS II—DISAPPEARING-FILAMENT

Leeds & Northrup Co. (1) Morse Type. This model was superseded in 1939 but many are in use and on the market. It is of the variable filament temperature type developed under the Morse patents. Construction of a late model is shown in Fig. 16 which brings out the telescope features of most portable disappearing-filament pyrometers. The image of the source is brought to a focus at *F* by the object lens *L*. The tungsten filament is placed in the plane of the image produced by the lens. The lamp current (from a battery in a portable case which contains the rheostat and the milliammeter) is adjusted until the brightness of the filament is equal to that of the object (see Fig. 31). Screen *N*, made of a suitable dark glass, is used for the measurement of temperatures above 2500°F. A different calibration is used with the absorbing screen (because the effective wave-length is altered) but the range without the screen and that with the screen overlap by several hundred degrees. This makes it possible to check the correspondence of the two scales within the overlapping portion.

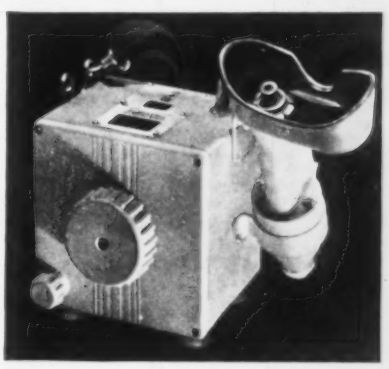


Fig. 17

Leeds & Northrup Co. (2) Potentiometer-circuit Type (Fig. 17). Brought out in 1939, this is not a new model of the L&N Morse type but a different instrument employing a potentiometer circuit (as do laboratory pyrometers such as that shown in Fig. 5). Its comparison lamp is of the new form described in Section 3: inclined flat sides, etc.; and the telescope as an optical instrument has been designed for industrial pyrometry and for use with the new form of lamps. Total weight of outfit is one-third that of the previous L&N model described above. The potentiometer circuit

itself (Fig. 18) is radically new and will no doubt find other applications where small currents must be measured rapidly and accurately. The lamp current can be adjusted by means of slidewire rheostat A when switch G is closed. The curometer slidewire B and its end-coil C. The potentiometer slidewire can be considered as being a variable shunt whose resistance is adjusted so that the product of the lamp current and the shunt resistance is equal to the emf. of the standard cell. It has been shown[1] that C and the shunted value of B can be determined for a lamp requiring known maximum and minimum currents to cover the temperature range. The scale associated with contact P can be calibrated in milliamperes or temperature. In optical pyrometers with direct-reading temperature scales the lamps must have uniform calibrations and some provision must be made whereby the same scale can be used with replacement lamps. In the new L&N instrument the adjustment of the temperature scale relative to contact P (which in effect changes C), and the replacement of shunt coil B', are all that is necessary when making a lamp replacement. The lamp is operated (by

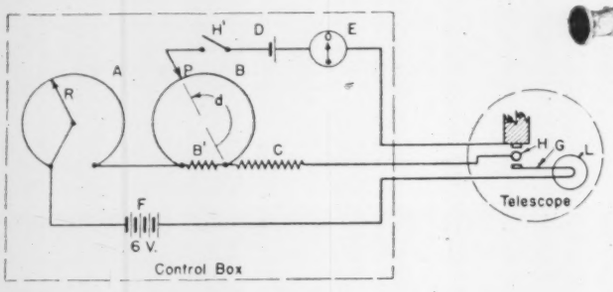


Fig. 18

four flashlight cells) at 20 to 60 milliamperes and over this range a change of 0.1% in current changes the filament temperature approximately 1°C. Galvanometer E has sufficient sensitivity to detect a 0.1% unbalance of the potentiometer. It is doubly protected against dust but even if magnetic dust should reach the movement it could only affect the sensitivity of setting, not the calibration of the pyrometer. It has been shown that a further increase in accuracy of temperature readings cannot be expected by making the current measurement more accurately.

As a result of the equal frequency of "charging" and "discharging" currents, a much larger current drain on the standard cell could be permitted than that of normal use. However, to minimize this source of error and to secure easy and rapid manipulation of the instrument, a mechanical device is used which keeps the potentiometer roughly adjusted for all lamp currents. This device consists of means for mechanically coupling the rheostat and potentiometer slidewire contacts in such a way that when the rheostat is moved (by means of the large knob, Fig. 17) to adjust the current, the potentiometer contact is carried with it in the direction required to maintain potentiometer balance, but when the potentiometer contact is operated (by the small knob) the rheostat contact remains at rest. Thus, it is possible to maintain a rough adjustment of the potentiometer while the lamp current is altered and, further, to balance the potentiometer without changing the current through the lamp. It can be seen from Fig. 18 that both contacts R and P must be near their right-hand limits for the maximum lamp current and corresponding potentiometer balance. If now the resistance of the rheostat A is no greater than is necessary under the condition that new cells are used at F, it is evident that if the potentiometer has been balanced for one position of R it will be automatically kept in approximate balance for all positions of R. Without the differential-clutch coupling, currents as large as 3000 microamperes could occasionally flow through the standard cell. In practice the mechanism is said to be so effective that when a series of readings of temperatures within a narrow range is being made it is unnecessary to rebalance the potentiometer after each reading. This new model is of course available with various styles of telescopes, with or without pistol grip, in Fahrenheit or Centigrade ranges, etc. No need to detail the numerous "features."

"F & F" (Fisher Scientific Co.). In this instrument, a "geometric wedge" is interposed between the source and the filament. Fig. 20 is a diagram of the optical system: a telescope with objective lens A and ocular lens D, lamp C with a hairpin filament mounted in the focal plane of the objective, the tip of the filament being viewed through the ocular. The filament operates at constant brightness. B is an adjustable wedge of absorbing glass, whereby the

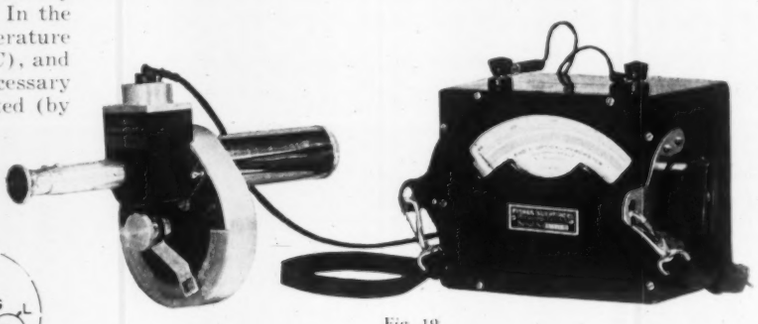


Fig. 19

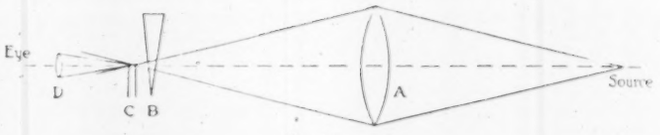


Fig. 20

brightness of the image of the source may bet set to a photometric match with the filament. In the actual instrument the wedge is not linear but semi-circular as in the "Pyro" instrument. The F & F wedge, however, is solid or geometric, the graduated density being produced by a variable thickness of dark glass. The absorbing glass is cemented to a similar semi-circular wedge of clear optical glass of the same refractive index. The combination is accordingly a disk of a uniform thickness. The pointer which indicates the temperature is directly connected to the wedge mounting. The standard range is from 1600 to 4000°F. This instrument was developed in America by the makers.

Foster Instrument Co. A portable telescope combined with ammeter but separate from the battery. Adjustment by controlling current through filament. A feature is the "lamp bridge unit" by means of which the whole scale is used. The lamp filament is made one of the arms of a Wheatstone bridge and the milliammeter is used as the bridge galvanometer. The method is that of the *semi-potentiometer* (see Sec. 9, Chapt. IX) and possesses the advantages of that circuit. At the same time, the units of bridge and lamp combined are made interchangeable. Another model is made without a lamp bridge unit system. Still another model is made with a separate indicator instead of the small one mounted on the telescope, and two rheostats: one for coarse adjustment and one for close matching.

"Pyro Micro-Optical" (Pyrometer Instrument Co.). This instrument's purpose is described by its name. Magnification being 20×, the outfit includes a rigid support and tripod, with worm-gear directional adjustments. One obvious use is the accurate measurement of temperatures of bodies of unknown or low emittance properties (for example, specimens of new materials on which research is being conducted) by placing such bodies in a blackbody furnace or by sighting into narrow cavities in such bodies. Another use is the pyrometry of molten metals by sighting the bottom of a closed-end refractory tube (of known emittance) immersed in the bath. A "precision ammeter" with built-in battery is in-

[1] *Review of Scientific Instruments*, Dec. 1939, pages 386-388. (Article by R. C. Machler of L&N giving detailed description of new circuit.)

cled. The instrument is furnished with the following scale ranges: 600-1600°C., 1600-3000°C., 3000-4000°C., or F. equivalent. An objective of 37-mm. aperture produces a reversed image of the object to be measured at about 6" (15 cm) distance; it is viewed through the ocular which acts as a microscope. The ammeter is intentionally not calibrated in temperatures as the scale would change every time a

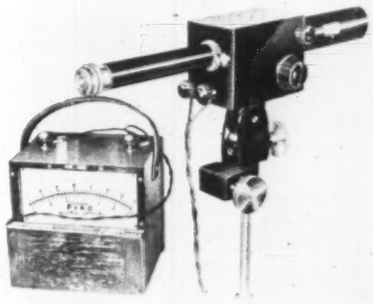


Fig. 22

lamp is replaced by a new one. The instruments are supplied with calibration curves from which the temperature corresponding to the galvanometer readings are taken. On special request, the ammeter can be furnished with a direct-reading temperature scale. The ammeter is compensated for variations in room temperature, and is of the suppressed-zero type in order to make better use of the scale. The zero adjuster is sealed and must be used only if the current is checked, in a suitably equipped laboratory, with a potentiometer.

The "*Pyro Remote Optical*" differs from the above in its lens system. It is used on sources which appear small at a distance and require a 15× telescope for proper viewing.

Siemens & Halske Cross-filament Type. In this instrument the lamp contains two crossed filaments of materials of different current-brightness characteristics intersecting (Fig. 21) at a temperature which serves as a comparison temperature, the two filaments then appearing equally bright. By

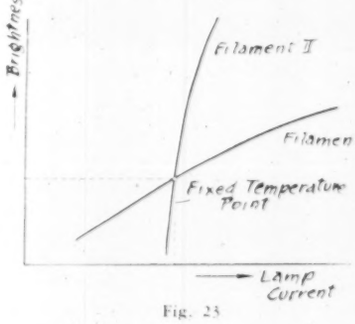


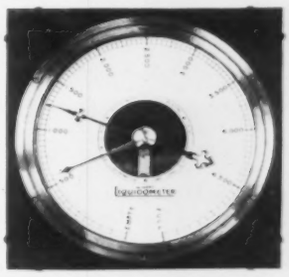
Fig. 23

means of an absorbing wedge between objective lens and lamp, the luminous radiation of the source is attenuated until the source and the cross-filament appear equally bright. This measuring method makes possible measurement without an electrical indicating instrument. In order to facilitate the adjustment of the two filaments to equal brightness, one is shaped as a broad ribbon so that it acts as background for the (other) round-wire filament. This adjustment is said to be made without difficulty to an accuracy of about 3°C.

Chauvin & Arnoux (France). A semi-self-contained instrument weighing a little over two pounds. Current supplied by either dry battery or lightweight storage battery slung from the shoulder. Distinctive features: (1) No dead space on scale, the zero at 600°C. coinciding with beginning of perception of light from source through the monochromatic filter. (2) Scale evenly graduated for 9/10 of its length. (3) Rheostat worked by one finger.

The Importance of Accurate Liquid Control Demands A LIQUIDOMETER The Dependable Tank Gauge for All Liquid Measuring

Many satisfied industrial users attest to the perfect year in and year out efficiency of their LIQUIDOMETER gauges. Convenient, hazard-free, 100% Automatic—these gauges insure accurate readings whenever required.



No pumps, valves or auxiliary units required to read levels. Balanced hydraulic transmission system completely compensates for temperature variations on communicating tubing. Accuracy unaffected by changes in specific gravity.

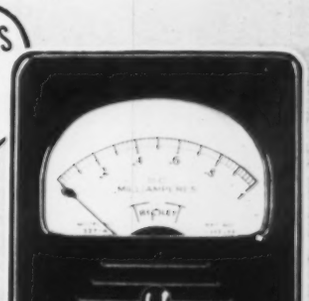
Approved for gauging hazardous liquids by Underwriters' Laboratories and other similar groups.

Models are available for REMOTE signals, automatic control of pumps, etc. Direct Reading models may also be installed where remote reading is not desired.

Write for complete details.

THE LIQUIDOMETER CORP.
36-27 SKILLMAN AVE. — LONG ISLAND CITY, N. Y.

TRIPLETT PRECISION INSTRUMENTS for EVERY REQUIREMENT



Round, Square, Fan or Twin Cases in 22 Styles

IN TRIPLETT'S entire line are instruments for every electrical measuring, indicating or control purpose.

★ D.C. Instruments are the D'Arsonval type with an extra light moving coil; time-proven magnets with pole pieces aligned to permanent precision accuracy; trussed metal bar bridges.

★ A.C. Instruments are the movable double iron repulsion type; with interchangeable coils.

★ Electro-dynamometer type instruments—a new line with developments assuring extreme accuracy and ruggedness. Wattmeters, voltmeters or ammeters.

MODEL 327-A

Model 327-A—One of Triplett's 22 panel instrument case styles. These precision electrical measuring instruments are provided in round, square, fan and twin cases—2", 3", 4", 5", 6" and 7". A complete line of portable instruments for exacting measurements also is offered.

★ Instrument relays — standard or special designs for electrified control purposes.

★ Instruments for special industrial applications—pyrometers, differential relays, directional locators, and a host of others.

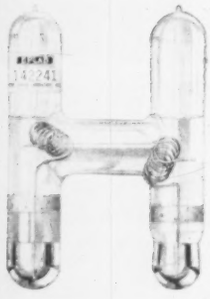
All have two genuine sapphire jewel bearings and every refinement marking the most approved instrument building practice.

Write for Catalog! Section 3212 Harmon Drive

THE TRIPLETT ELECTRICAL INSTRUMENT CO.
Bluffton, Ohio

MAKERS OF TEMPERATURE CONTROL APPARATUS—

CHOOSE THE FINEST



INSIST ON EPPLEY

The accuracy and efficiency of industrial control apparatus utilizing the potentiometric system depends to a large extent upon the reliability of the standard cell.

Make sure that you have the best. Use only Eppley cells. Our twenty-four years of experience are your guarantee of satisfaction.

EPLAB

THE EPPLEY LABORATORY, INC.

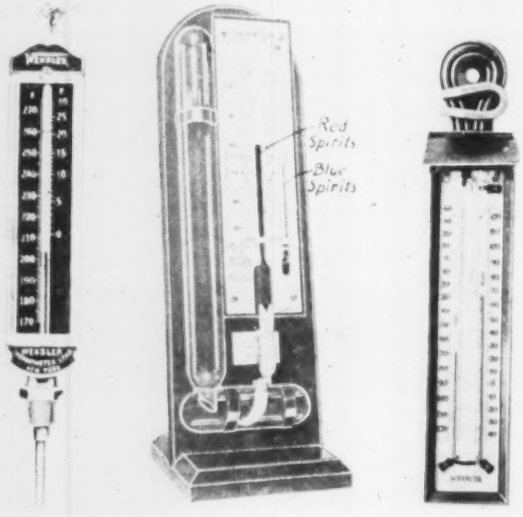
SCIENTIFIC INSTRUMENTS

NEWPORT, R.I.

U.S.A.

Thermometers Psychrometers

Hygrometers Hydrometers



No. 169. For pressure-cooking processes; with 2 scales: 170-270°F. and 0-30 lbs. pressure. Nine-inch scale length.

NEW Bailey-Parsons Thermihiter reacting to effects of temperature, humidity and air circulation, providing best guide for air conditions in workrooms, offices, etc.

No. 326. Max. & min. registering thermometer in 12" shelter type copper case. Approx. range minus 40 to 120°F.

Weksler Thermometers are offered in FOUR different styles of glass: White enamel back; yellow enamel back; Hespe; red-reading mercury.

WEKSLER THERMOMETER CORPORATION

535 PEARL STREET, NEW YORK, N. Y.

(b) Wedge or Extinction

EXTINCTION OF TOTAL LUMINOUS FLUX

"Wedge" (The Optical Pyrometer Syndicate). This English instrument is self-contained and shaped like a pistol, consisting as it does of a telescope and a long housing in which the straight wedge is moved up or down. The makers state that the prism is made of specially prepared dark glass, so arranged that it cuts off the light emitted by a heated body at various temperatures. For example—in looking at a heated bar iron, supposing the temperature to be 1000°C., then on turning the screw the thicker part of the prism comes gradually into the field of vision, the bar appears gradually darker till at a given point the object entirely disappears; then, "on looking at the scale, the pointer will be seen at 1000°C." A little practice is required to decide the exact point at which the object disappears.

"Pyroversum" (Ströhlein & Co., Germany). Same principle as the English "Wedge" but simpler construction. It resembles a slide rule: A frame about 7" long encloses a shaded glass ranging from clear at one end to opaque at the other. One looks through a hole in the sliding eye-piece, which one pushes along the frame until the glow becomes invisible. One then reads the temperature by the position of the slide on the scale along one edge of the frame.

EXTINCTION OF MOST-VISIBLE WAVE-LENGTH

"P2" (Same make). Same idea as the "Pyroversum" but minus the sliding eye-piece. The framed glass is held between the eye and the glowing object; it is moved until the glow vanishes, and one marks the place on the graduated edge with one's finger. The glass is green in its "effective wave length" so that extremely high temperatures can be measured fairly closely by an experienced observer—if the source is nearly a blackbody, because standard emissivity corrections (for $\lambda = 65\mu$) are inapplicable.

(c) Color

"Pyrovisor-H." This German instrument (American Demag Corp., agents) closely resembles the "Pyroversum" in construction, but it is used to measure the temperature of the source by determining the ratio of the intensity of an almost monochromatic band in the red end of the visible spectrum to that of a similarly narrow band in the green portion. This ratio is ascertained by means of what may be described as a green-red double wedge, one end transmitting more green than red and the other end more red than green, so that there is a definite green-red ratio for every point along this strip of glass. We quote:

"The temperature of the body is therefore measured simply by finding that spot in the light filter where neither the green nor the red color is distinctly visible but where both colors fuse and become white in appearance . . . For very accurate readings, find first with one eye the approximate spot where both colors fuse together, then switch over to the other eye and determine the correct spot of the fused colors by moving the color glass slightly in both directions until the exact location is found where the color appears neither red nor green. It is important in order to avoid color fatigue of the eye, not to look at the glowing body for too long a time through a part of the glass which shows a distinctly green or red color. It will take a few days to become fully accustomed to the Pyrovisor and to obtain quick and accurate temperature readings."

"Bi-Optical" (Pyrometer Instrument Co.). Unlike the device just described, this instrument is designed for laboratory and research work and comes with the rigid support shown in Fig. 23. It has two purposes: (1) the measurement of color temperatures of illuminants; (2) the measurement of temperatures of bodies of unknown emittance properties, these bodies being assumed to be graybodies at high temperatures—an "if" which does not appear in the 2000-word description from which the following is abstracted:

The filter is composed of two filters placed one behind the other. The first filter is of plane form, and completely screens certain parts of the spectrum of the source. Behind this filter is placed a second filter not of plane form, which transmits part of the colors allowed to pass by the first filter but absorbs the remainder to an extent which increases gradually

In consequence of the variations in the degree of absorption of different colors, there is produced a mixture of light rays which has at all points a different spectral distribution and therefore a different color. The colors which pass through the first filter thus merge at a particular point of the second filter

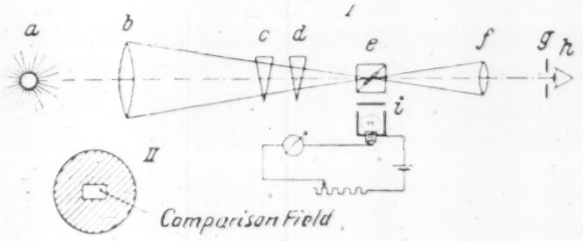


Fig. 24

to form a mixed or neutral color. The part of the filter at which this mixed or neutral color is formed is dependent, in a filter of given transparency, on the spectral distribution of the rays emitted by the source and therefore on the temperature thereof. The point at which the mixed color appears is employed as an index of the temperature of the source.

The employed colors, green and red, produce, mixed in a definite ratio, the impression "white" in the eye, the best suited mixed color as recollection color. Since the eye possesses the greatest sensitivity for green and orange, this mixture is the most suitable one for the purpose.

The comparison field of illumination—in the form of a "yellowish-white" luminous rectangle—possesses, after complete adjustment to color and brightness, the same spectral energy distribution as the field to be measured. The device for adjusting the brightness serves to determine the blackbody temperature.

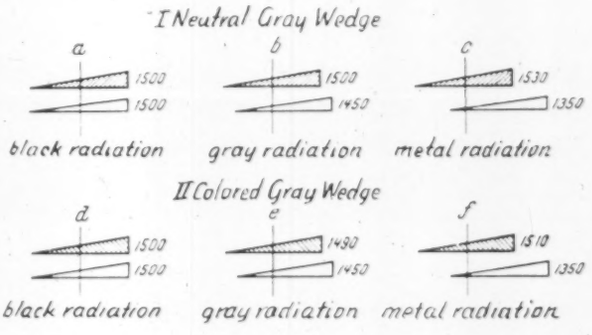


Fig. 25

The light of source *a*, Fig. 24, falls through telescope objective *b*, ocular *f* and diaphragm *g* into the eye of the observer *h*. Bichromatic color wedge *c* is inserted into the path of the ray which allows only the red and green light to pass and permits, furthermore, change by shifting the intensity ratio of these colors as it absorbs the two colors with increasing thickness to a different degree. Neutral wedge *d* allows a change in brightness. Photometric *e* permits matching illumination of comparison lamp *i* and principal beam. Parts *c* and *d* are inserted each by an adjusting scale ring so that both color and brightness of the field to be measured agree with the comparison field. The color temperature is established by means of the color wedge *c* and the temperature corresponding to the blackbody by means of the gray wedge. The difference between the two scale indications shows whether radiation of a blackbody or of a bright metal exists.

Fig. 25 shows the position of the two wedges with respect to each other for blackbody (*a*), graybody (*b*) and radiation of bright iron (*c*). For blackbody radiation the two instrument scales agree. For graybody radiation the color temperature coincides with the "true" temperature while "blackbody" temperature is considerably lower. In order to have agreement between color temperature and "true" temperature also for the radiation of bright metals, the color temperature read on the instrument is approximated so closely to the "true" temperature with a colored gray wedge that the color temperature can be considered in all technical cases—that is also for radiation of bright iron (*c*)—as the "true" temperature (*d*, *e*, *f* in Fig. 25).

Eastman Color Temperature Meter (*Eastman Kodak Co.*). Chief purpose of this instrument is to determine the color temperatures of illuminants in order to regulate lamp voltages or otherwise provide the correct quailty of light for indoor color photography, or select the correct filter for the camera lens. Therefore it *can* be used for measuring color

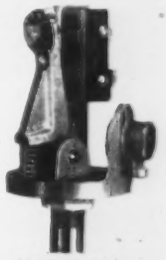
BURLING

HEAT CONTROLS

RAPID • ACCURATE

MODEL D

Temperature Range—100 to 1400 deg. F. A rugged accurate instrument easily installed in FURNACES, OVENS, TANKS, or METAL POTS with suitable fittings. A turn of the outside knob changes temperature setting instantly.



MODEL V-1
(with cover removed)

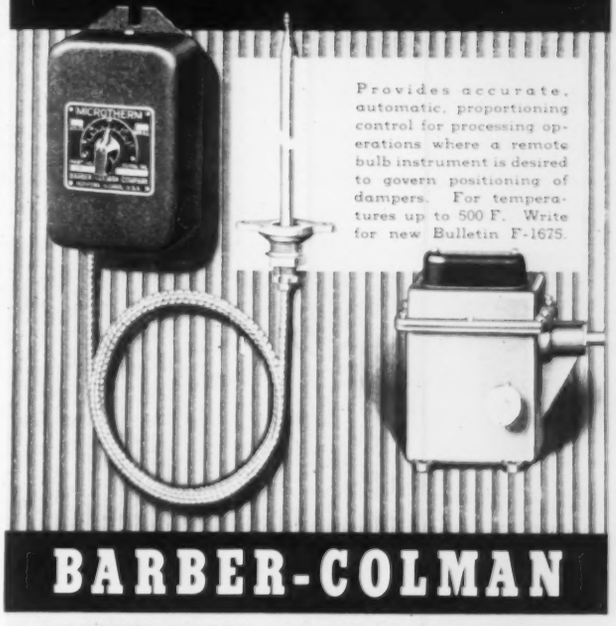
Model V-1 with differentials from ± ¼ to ± 5 deg. will give close control in OVENS, TANKS, FURNACES, or CHEMICAL PROCESSES. Temperature range from—100 to 600 deg. F.

SEND FOR NEW CATALOG!

BURLING INSTRUMENT CO.

251-253 SPRINGFIELD AVE. NEWARK, N. J.

Bulb-type Micro-Control
...for DAMPERS!



Provides accurate, automatic, proportioning control for processing operations where a remote bulb instrument is desired to govern positioning of dampers. For temperatures up to 500 F. Write for new Bulletin F-1675.

BARBER-COLMAN

ELECTRIC SYSTEM OF TEMPERATURE CONTROL

BARBER-COLMAN COMPANY

ROCKFORD, ILLINOIS

temperatures of sources other than studio lights, etc. It employes a diametrically-divided circular field, half of it illuminated by the source through a filter of yellow effective wave-length, the other half through a green-to-red tapering filter as in some of the above-described instruments and devices. This second filter is rotated until both halves appear yellow and match in color and brightness; then the color-temperature scale attached thereto is read. The instrument comes with a special candle which burns with known spectral distribution and is used for setting the scale (to suit the eye of an individual observer) in conjunction with an accommodation adjustment filter. When viewed through this filter the candle flame has an effective color temperature equal to that marked on the filter mount. By means of the accommodation scale on the instrument a number of observers, each knowing his own accommodation factor, can then use the instrument without having to repeat this operation. Several brief passages from the instruction book are of such distinct interest to pyrometrists that they are quoted:

Values of color temperature can only be applied strictly to sources having an energy distribution resembling that of a perfect radiator. Tungsten filament lamps fall closely enough in this class. Some are lamps, and other sources having discontinuous spectra should be said to have *equivalent* color temperatures, provided their color matches that of a perfect radiator. Discharge lamps, such as mercury, neon and sodium tubes, which have characteristic line spectra, cannot be said to have color temperatures.

Conditions of fatigue and eye strain make it important that the accommodation setting be redetermined occasionally. In measuring the color temperature of strong light sources such as studio lamps, the field may be too bright to permit an accurate reading. For this purpose the Eastman Color Temperature Test Paper is provided with the meter. Hold a strip of this special paper in the full beam of the light and then direct the Color Temperature Meter toward it, and read the reflected light. The white paper supplied for this purpose is so chosen that the color quality of the light reflected from it differs only slightly from the color quality of the light falling upon it. *Ordinary white paper and other white objects will by no means be satisfactory for this purpose.* When the paper is used, 75° should be subtracted from the meter reading in order to obtain the color temperature of the source itself. The value 75° applies only to color temperatures about 3,000°K. The actual deduction to be made will depend on the color temperature indicated by the meter. At about 1,000°K. the deduction will be 130°, at about 5,000°K. the deduction will be 20°. Deductions for intermediate color temperatures should be roughly proportional.

Source	*Color Temperature, °K*
60-watt vacuum tungsten filament lamp	2,500
100-watt gas-filled tungsten filament lamp	2,865
500-watt gas-filled tungsten filament lamp	2,960
1,000-watt gas-filled tungsten filament lamp	2,990
500-watt projection lamp	3,190
G.E. Mazda Lamp 3200 °K	3,200
Mazda C.P. Lamps	3,280
1,000-watt Photoflood Lamp	3,415
250-watt Photoflood Lamp	3,414
Photoflash Lamp, No. 21	3,800
White flame carbon arc	5,000
Mean noon sunlight at Washington, D.C.	5,400
High intensity sun arc	5,500

The color temperature of a studio lamp varies with the voltage: about 10°K per volt.

WARNING. It must be emphasized that people who are color blind will not be able to use the meter, and that some others who have certain abnormalities in their color vision will not be able to use it.

CASE SCHOOL OF APPLIED SCIENCE

CLEVELAND, OHIO

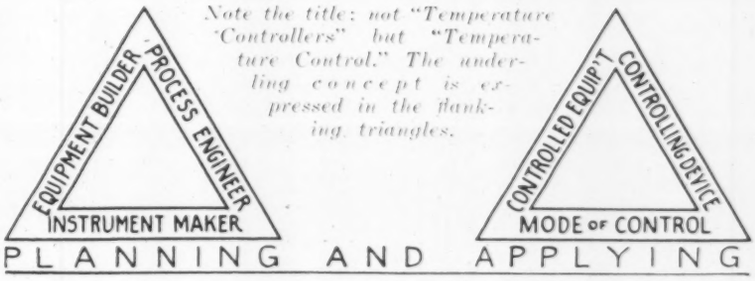
DEPARTMENT OF CHEMICAL ENGINEERING

For further details, address L. O. Miller, Ass't Prof. Chem. Eng'g., Case School.

TENTATIVE PROGRAM
CASE LECTURE SERIES ON INDUSTRIAL INSTRUMENTATION

Lecture No.	*Evening*		*Speaker*
		A. General Introductory Lectures	
1	Tues., Feb. 4	Introduction. Classifications and Generic Properties of Measuring and Controlling Instruments.	M. F. Behar, Editor *Instruments.*
2	Thurs., Feb. 6	General Principles of Automatic Control.	J. J. Grebe, Dow Chemical Co.
3	Tues., Feb. 11	Functional Classification of Electrical Instruments.	P. L. Hoover, Dept. Elect. Eng'g, Case School.
4	Thurs., Feb. 13	Functional Classification of Electrical Instruments.	P. L. Hoover.
5	Tues., Feb. 18	Principles Involved in Air-operated Controllers. (Demonstration of instruments)	Brown Instrument Co. representative.
		B. Temperature Measurement and Control	
6	Thurs., Feb. 20	Fundamental Principles of Temperature Measurement.	Dept. Chem. Eng'g, Case School.
7	Tues., Feb. 25	High Temperature Measurement and Control Instruments. (Chiefly Optical and Radiation.)	Brown Instrument Co. representative.
8	Thurs., Feb. 27	Lower Temperature Measurement and Control Instruments. (Chiefly Thermocouple and Expansion Bulb.) (Demonstration of instruments)	Wheelco Instrument Co. representative.
		C. Pressure Measurement and Control	
9	Tues., Mar. 4	Principles of Pressure Measurement.	Dept. Chem. Eng'g, Case School.
10	Thurs., Mar. 6	Pressure Measuring Elements, Recorders and Controllers. (Demonstration of Instruments)	Taylor Instrument Co. representative.
		D. Fluid Flow Measurement and Control	
11	Tues., Mar. 11	Principles of Fuid Metering—Bernoulli's Principle (Calculations.)	Dept. Chem. Eng'g, Case School.
12	Thurs., Mar. 13	Principles of Fuid Metering—Meters, Calculations and Calibration.	Dept. Chem. Eng'g, Case School.
13	Tues., Mar. 18	Instruments for Measurement and Control of Fuid Flow. (Demonstrations including liquid level controls)	Foxboro Co. representative.
		E. Hydrogen Ion Measurement and Control	
14	Thurs., Mar. 20	Fundamentals of pH Measurement.	Dept. Chem. Eng'g, Case School.
15	Tues., Mar. 25	Instruments for Measurement and Control of pH. (Demonstration of instruments)	Leeds & Northrup Co. representative.
		F. Other Fields	
16	Thurs., Mar. 27	Principles and Applications of Photoelectric Cell Equipment.	Wheelco Instrument Co. representative.
17	Tues., Apr. 1	Atmospheric Temperature and Humidity Control.	Minneapolis-Honeywell Co. representative.
18	Tues., Apr. 8	Automatic Gas Analyzers.	To be announced.
19	Thurs., Apr. 10	New and Specialized Instruments.	General Electric Co. representative.
		G. Plant Installations	
20	Tues., Apr. 15	Instrumentation in Petroleum Industry. (Where to Control.)	James Kearney, Austin Company.
21	Thurs., Apr. 17	Instrumentation in the Petroleum Industry. (How to Control.)	Foxboro Co. representative.
22	Tues., Apr. 22	Instruments for the Boiler Room.	Bailey Meter Co. representative.
23	Thurs., Apr. 24	Instrumentation in the Metallurgical Industry.	To be announced.
24	Tues., Apr. 29	Telemetering.	Bristol Co. representative.

Some ABC's of Automatic Temperature Control



Note the title: not "Temperature Controllers" but "Temperature Control." The underling concept is expressed in the flanking triangles.

Another fragmentary foretaste of the forthcoming revised edition of "T.M.&C." This part, however, stands largely as written eleven years ago.

By M. F. BEHAR

1. General Considerations.

A thermometer or pyrometer indicates what the temperature *is*. A recorder shows what the temperature *was*. An automatic temperature controller deals with the future: "Set it and forget it"—the old slogan of a pioneer controller maker—aptly sums up its liberation of man-power for more productive occupations.

Every temperature controller starts with a thermal system. Hence an acquaintance with the characteristics of the classes and types of temperature *measuring* instruments is required for an adequate understanding of automatic temperature control—controlling instruments, controlled devices and other elements of temperature control systems. Since thermometers and pyrometers have been dealt with in preceding chapters, their respective advantages, limitations and other characteristics need not be dwelt upon here, but these characteristics must be borne in mind. For example the differential-expansion thermometers (Chapter V), when considered as thermometers, are generally considered to consist of "not-so-accurate" rod types and "accurate" bimetal-coil types, but when we consider them as the thermal or primary systems we immediately revise our judgment: the rods are "powerful," the coils are "weak."

No controller can be better than its primary measuring element!

The thermal systems embodied in all temperature controllers obey the same physical laws as are obeyed by the corresponding indicating thermometers and pyrometers, but practical requirements have imposed far different forms in most cases. It is of interest that the *difference* between a temperature indicator and the corresponding thermal system of a temperature controller (for the same given range) is usually small for high-temperature applications, and becomes greater as the range lies lower. Thus in quickly glancing over the entire field of temperature control, one observes that pyrometric control systems start off with indicating and recording pyrometers to which a few extra parts have been added; whereas in the "hot-water" working ranges we meet a great variety of thermal systems which, while they have bulbs and connections identical with those of the indicators and recorders, differ widely inside the instrument case on the panel board (when there is anything at all resembling a case); and finally, in the field of refrigeration control, we come across specially designed thermal systems which, while employing one of the applicable principles of thermometry, resemble thermometers as little as a bell-ringing push-button resembles an automatic motor starter.

Since automatic temperature control won noticeable acceptance in industry with the turn of the century, the trend toward simplification—*where temperature indication was not required of the controller*—resulted in a variety of inexpensive thermostatic devices. These invaded the domestic field—whereupon competition arose and brought about even greater simplification. It was discovered long ago that whereas a temperature indicating instrument must be accurate over its entire range, the sensitive element of a thermostat need only be "accurate" over a narrow range. The on-and-off mode of control of the simpler devices further reduced the number of design factors. Quantity production led to standardization and an ever-increasing number of applications have been discovered, developed and exploited in the home, on the farm and in the office, as well as around the plant.

A parallel line of development combined the sensitive element with the actuating element: the same part which responded to the temperature turned the heat on and off as required. This simplification has reached what may be its triumphant climax in the Westinghouse "Klixon" for preventing over-heating of electrical appliances—a bimetallic disk which suddenly bulges at a certain temperature, and suddenly flattens back a few degrees lower, with sufficient strength to work the switch.

At the other extreme, we might mention certain systems of temperature control for blast furnaces and other large and important industrial applications—but we do not imply that these constitute the climax of complexity and cost.

At any rate such examples show the extent of the field of automatic temperature control. We can only deal with the *industrial* process temperature controllers—with the devices themselves without attempting to deal with their specific industrial applications—and sketchily at that . . . and *control* must be discussed before *controllers*.

Another thing which strikes one who travels his glance over the field of temperature control, starting with high temperatures and ending with refrigeration, is that the number of *specialized* and *standardized* thermal systems and relay systems is the greatest in the middle, tapering off at both ends. This is in exact accordance with the "penetration" of temperature control in winning the confidence of industry. As long ago as 1919, Fairchild and Foote of the Bureau of Standards, addressing the A.I.M.M.E. on "High Temperature Control," declared that "the greatest progress has been made in those industries in which the lower temperatures are used, particularly below 500 C. In this lower range automatic control has been highly developed."

2. Suitable Equipment Required.

This significant utterance, still applicable today, may be paraphrased; and it may be said that the development of automatic controllers is bound up with the development of automatic control. As in other fields of invention, the device which is ahead of its time can make little headway. Great as has been the extension of temperature control in industry, it is in its infancy, and its adolescence waits upon the growth and manifestation of a greater interest on the part of precisely that group of industrial engineers who would reap its greatest benefits. There is a limit, after-all to the mind-reading ability of the instrument maker and to the power of advertising and salesmanship. The further development of automatic control and of controllers demands, first, a greater temperature consciousness on the part of prospective users of temperature controllers in industry;

second, the granting of a freer entrée to instrument men by the former and, third, a more receptive attitude on the part of the equipment mnaufacturer. It is high time for builders and manufacturers of furnaces, kilns, melting pots and tanks, lehrs, ovens, boilers, kettles, stills, towers, vats and of all other diversified industrial equipment, to realize that some among them are holding up the procession. It is high time for all to follow the example of a few who make "controllability" a part of design routine.

Every reader of this book probably knows of some temperature control installation which was turned off or disconnected "because it did not work." The chances are that the controller was not given the proper opportunity to fulfil its mission, the reason being possibly that it was abused and probably that the equipment on which it was installed was not suitable for its application. Articles on automatic temperature control frequently appear in industrial publications and their authors are prone to make the general statements (1) that any piece of equipment which cannot be controlled by hand cannot be controlled automatically —which is correct—and (2) that where temperature can be controlled manually it can be controlled automatically—which is wholly untrue with reference to the very applications which today still resist the conquest of automatic temperature control. It isa fact that in the case of several high-temperature processes *manual* control really means *visual* control, and that the furnace and kiln builders stick to their designs which were developed for the benefit of the old-time pre-pyrometry metallurgists and ceramists who worked by eye!

Such furnaces and kilns will have to be re-designed by or with the assistance of three groups of experts: (1) specialists in the proper application and location of thermocouples and radiation receivers which "feel" the temperature which is to be controlled; (2) specialists in the application of power-driven regulating devices; and (3) specialists in the combining of these two elements—engineers who might be called the liaison officers experienced in the performance characteristics of temperature control applications.

Finally, we must not forget the operating man's viewpoint. If the equipment is such that temperature control is not really automatic, he will be the first one to complain . . . or make trouble.*

2. Proper Installation Required.

Next to the application itself, which sometimes precludes automatic control and always limits the number of suitable temperature control hook-ups, the manner in which control is applied is a prime consideration. In many cases the man in charge of a process may cry in vain for close control, because even if he selects a type and make of automatic controller which, with its appurtenances, is likely to give him fairly good results, the proper installation of this temperature control system might require that the instrument company's engineer spend an entire week on that application . . . after spending months studying the process. That is one reason why automatic control has not yet been adopted for certain processes, especially for certain high-temperature processes. Not only have some furnaces not yet been sufficiently modified for the application of temperature control devices, as mentioned above, but the furnace builders, the instrument makers, and the metallurgists have not yet pooled their knowledge sufficiently to apply control in a scientific way to many furnaces which *could* be controlled. Instrument sales and service engineers cannot be expected to possess intimate knowledge of all temperature processes and of all types of temperature process equipment. Team work is required. Team work means "getting the signals," means understanding one another. It is too much to expect of processing equipment builders and users that they learn the language of the instrument fraternity. They need not even learn much about controllers. But they must understand *control*. Especially the industrial process man: his job —let it be repeated—is the conquest of variables, which is another name for control of all conditions. Temperature being an important condition he cannot afford to "leave it to the instrument salesman."

4. The "Four Requirements."

A thermometer or pyrometer merely reports—as would a subordinate sent by a manager to look over a situation; an automatic controller takes action—as would an alert executive to whom reports are submitted. All controllers are active, operating, "live" devices, to be judged by active performance, not by passive qualities.

The proper performance of a controller depends, as does that of a manager, on the correctness and timeliness of the infomation it receives, and on the limits within which its power may be exercised. Summarizing, we lay down the basic requirements for automatic control of process temperatures in industry:

(1) The temperature to be controlled, or its variation, must be measurable.

(2) The primary element of the automatic controller must be suitable for the measurement involve dand must be properly installed.

(3) The power device commanded by the control instrument must adequately control an adequate source of heat supply.

(4) The measuring means must command the corrective means effortlessly, i.e., without having its own measuring properties impaired.

Obvious and simple as are these four basic requirements, they are sometimes lost sight of in the maze of engineering details that have to be taken into account when working out elaborate installations.

5. Possible Classifications of Industrial Automatic Temperature Control Devices and Systems.

The above heading suggests one classification—the word "Industrial" excluding domestic devices.* Eve nrestricting our scope to the industrial temperature controllers, space limitations prevent their being treated exhaustively as mechanisms; there is a better use for this space than encyclopædic cataloguing.

Another possible classification is by the usual designations and what they stand for, but the nomenclature has not been standardized and as a matter of fact it would be hard to draw lines separating thermostats, heat regulators, temperature regulators, automatic temperature controllers and automatic temperature control systems—not to mention devices called by other names.

Another classification is into non-indicating, indicating, and recording automatic temperature controllers, these designations being self-explanatory. Usages vary somewhat in the application of modifications of these names. In the thermometric range we find such terms as "indicating controller" and "recorder-controller," both of which are self-explanatory. In the pyrometric range, "controlling pyrometer" is generally understood to mean an instrument which also indicates, while "recording controller" and "controlling recorder" are both used—seldom "recorder-controller." "Controlling potentiometer" is the usual designation when the system is based on that calss of instrument, the reason being that self-balancing potentiometers with control features are applicable without modification for the regulation of other conditions beside temperature: humidity, flow, level, pressure, gas analysis, pH, speed, light, etc. Moreover, self-balancing *bridges* with control features are commonly called "control potentiometers"—no doubt because they present the same outward appearance and are less numerous.

"Self-contained" and "distance" or other such terms suggest a simple and practical distinction between instruments

*Excellent discussions of design factors with regard to high temperature distribution and control are found in numerous papers presented at meetings of the A.S.M., A.S.M.E., A.I.M.E., A.I.Ch.E. and other societies in recent years; and printed in their respective *Journals* and *Transactions*. These discussions show the obstacles in the way of applying automatic temperature control to furnaces where gradients exist, making it difficult to select the one location where the temperature is representative and where at the same time it is indicative of both changes in *demand* and effects of changes in supply.

*As a matter of fact, some of these—especially those that come within the jurisdiction of and comply with the various electrical and mechanical standards sponsored by the A.I.E.E., N.E.M.A., N.E.L.A., Underwriters' Laboratories—are better designed, better constructed, operate better and sometimes necessarily cost more than some of the simpler forms of industrial heat regulators.

located at the point of application and those with connecting tubes or leads running from the bulb or couple to another element of the system; or else the distance feature may refer to the operation of a valve at a distance from the instrument case which may be located on a panel board.

One logical classification is into self-operating instruments or appliances or *devices;* and control *systems* which utilize relays. By "self-operating" is meant that the primary element responds to temperature with sufficient force to operate a valve, damper, etc., for controlling temperature. If the primary element actuates a pilot valve or a contact, the controller belongs to the relay class. The "instrument" proper forms part of a hook-up which must be considered as a whole: the instrument *commands* the power which *controls* the heat supply and hence the temperature.

This suggests a classification according to form of power. Such forms will be discussed below but it will be hard to follow a definite classification because some systems would belong to two and even three classes. For example, a primary element may actuate an air valve relay which actuates an electric relay which in turn commands the energized device.

"The energized device"—this does not mean the valve or damper but the *power device* or *power unit;* and here we have still another basis for classification: Diaphragm, solenoid, cylinder-and-piston, electric motor, etc.

The Power Device or Unit is the "muscle" of any *relay type* of automatic controller commanding an element such as a valve or rheostat which requires expenditure of energy for its positioning, operation, etc. (in a self-operating controller the power device is *not* a distinct element.) Examples of power devices or units are electric, pneumatic or hydraulic servo-motors, pneumatic diaphragms, etc. The power device or unit is to be distinguished from the final control element. The common terms "control valve," "diaphragm-motor valve," etc., denote the *combination* of a power device and a controll*ed* element. For example, in a "control valve" of the diaphragm type, the power device is the pneumatic diaphragm "top" and the controlled element is the valve proper.

And last but not least, a classification of the valves and other medium-controlling appliances. Certainly not least, because this final element of the temperature control system often determines the choice of the others.

To tabulate all the possible combinations in a comprehensive and systematic way would be both tedious and useless. An idea of the number of possible hook-ups may be had by multiplying the number of types of primary elements (about 20) by one-quarter of the number of classes of relay methods (about 8*), multiplying the product (about 40) by one-quarter of the number of forms of power devices (about 20) and multiplying this product (about 200) by one-quarter of the number of varieties of finally operated valves (about 400). We get something like 20,000 possible combinations, and only one-quarter of the number was used at every step of this process.

Or, to put it in another way, you may start with any one of the 20-odd types of primary elements, have it actuate one of a choice of two (out of 8) relay systems, then select any one of five (out of 20) power devices capable of operating any one of 100 (among 400) valves.

Omitting the valves we have the conservative number of 200 wholly different types of automatic temperature controllers. We could even call them classes because they would all be mutually exclusive. And all this without mentioning the possibilities in the way of direct and reverse action at each step—which gives us $200 \times 2 \times 2 \times 2 = 1600$.

Ordinary self-operating controllers, those combined with valves, cannot strictly meet the Fourth Requirement (see Section 4) but the effort exerted by their combination measuring-and-operating elements is minimized by the use of balanced valves, etc., and their applications still outnumber the applications of all relay control systems. The most important process-control applications, however, require the use of relay types, some of them with elaborate amplifying systems whereby the moving element of the measuring system

*Seven classes if we include "steam" with "pneumatic," eight if it is recognized as a class by itself.

Built For *Your* Job - - - "Radio Principle" Temperature Controllers

"Radio Principle" Temperature Controllers are available for all ranges between 0 and 3600 F. or equivalent C. All the Controllers listed below incorporate the famous Wheelco "Radio Principle."

Potentio-trols—Potentiometer Controllers. Bulletin A2.

Capacitrols—Pyrometer Controllers. Bulletin D2.

Therm-otrols—Thermometer Controllers. Bulletin G502.

Resistance Thermometer Controllers—Bulletin G202.

Proportioning Controllers — Available with any of the above controllers.

Limitrols—Automatic Limiting or Shut-off Controls. Bulletin D202.

Potentio-trol

Write for Free Bulletins Today!

Wheelco Instruments Co.
1929-33 S. HALSTED STREET . . . CHICAGO, ILLINOIS

Accurate . . . Sensitive TEMPERATURE CONTROLS

AVAILABLE IN SIZES AND TYPES TO MEET MOST REQUIREMENTS. THESE H-B CONTROLS ARE DESIGNED TO MAKE ACCURATE TEMPERATURE CONTROL A SIMPLE MATTER FOR THE OPERATOR.

RELIABILITY . . . backed by the stand ard H-B warranty of satisfactory service

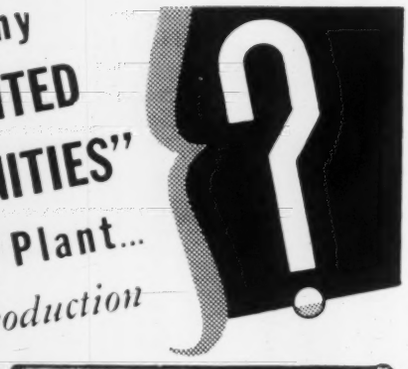
SENSITIVITY . . . within 1 10 of 1 F of the specified control points or ranges

RANGE . . . any holding points or ranges, as specified, between −30° F and 500° F

● Blue Book Part 4, fully describing the H-B line of Temperature Controls, is illustrated and heavy bound for filing durability . . . free on request. If you haven't received a copy of Blue Books Part 3 and 5 fully describing the H-B Double Diamond line of Industrial Thermometers and Thermo-Hydrometers . . . just ask for them on your letterhead; no obligation.

H-B INSTRUMENT CO. Inc.
PRECISION SCIENTIFIC & INDUSTRIAL INSTRUMENTS
2506 NO. BROAD ST., PHILADELPHIA, PENNA.

How Many "UNCOUNTED OPPORTUNITIES" in YOUR Plant... *for Closer Production Control*



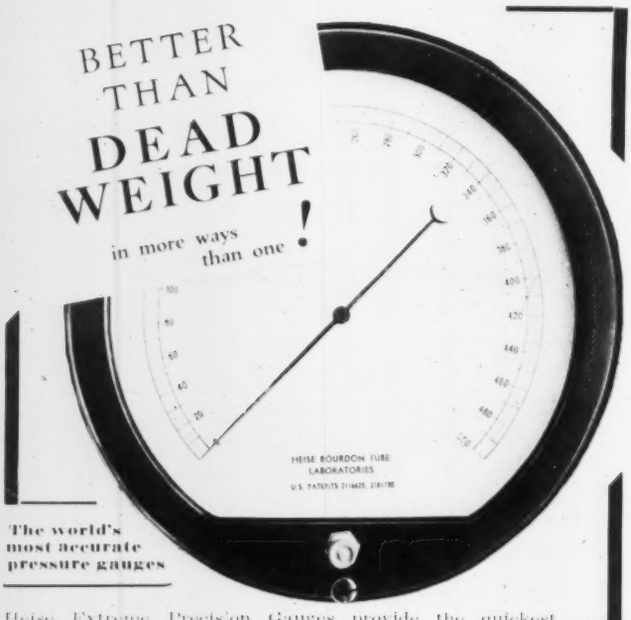
Are there machines and processes on which you would like to get *accurate* production records by the hour, day or week? Veeder-Root Counters can give you these records . . . mechanically or electrically . . . in any terms you want: revolutions, strokes, operations, pieces, trips, speeds, volumes, lengths, hand-movements, light-flashes . . . or what have you? And these "facts in figures" will point out ways to tighten production and cost control, and to schedule work more efficiently. WRITE.

VEEDER-ROOT INC., HARTFORD AND BRISTOL, CONNECTICUT

Offices in Boston, Chicago, Cincinnati, Cleveland, Detroit, Greenville, S. C., Los Angeles, New York, Philadelphia, Pittsburgh, St. Louis, San Francisco, Montreal, Canada, Buenos Aires, Mexico City, London, Paris, Tokio, Shanghai, Melbourne

Veeder-Root COUNTING & COMPUTING DEVICES

BETTER THAN DEAD WEIGHT in more ways than one!



The world's most accurate pressure gauges

Heise Extreme Precision Gauges provide the quickest *reliable* way of testing: (1) new ordinary gauges, (2) inspectors' gauges, (3) for faster results where dead weight testers have been used. Indispensable to manufacturers of equipment which includes gauges. *Important feature:* revolving dial simplifies calculations by eliminating tare figure. Zero setting is instantaneous from front of bezel and self locking.

Note. Prices are surprisingly low. Example, $120 for a ten-inch (11¾" O.D.) gauge with 500 graduations.

HEISE Bourdon Tube Laboratories

275 NOBLE AVE. BRIDGEPORT, CONN.

In Collaboration with The A. H. Emery Co.

is altogether free from mechanical drag, electrical attraction-and-repulsion effects, or other influences.

An obvious solution of the drag problem is exemplified in those controllers (both self-operating and relay) in which the measuring system has no moving parts at all. This leads to the following classification of all automatic control systems according to *temperature measuring systems:*

Class I. Kinetic (or Dynamic)	All measuring systems in which variations in the controlled temperature are represented by mechanical displacements.
Class II. Static	Saturable magnetic circuits. Electronic devices. Circuits utilizing non-linear resistance.

Another solution consists in the elimination of moving parts from the power unit (e.g., by use of electronic devices) as exemplified in various temperature controllers for electrically-heated processing apparatus.

An ideal solution (not *the* ideal, because of various shortcomings such as absence of adjustment dials and other process-control conveniences) is to have no moving parts in the measuring system, in the control means or in any other element of the automatic controller.

6. "Sensitivity" and "Sensitiveness."

Perfect automatic control may be said to be an unattainable ideal for the reason that a controller only starts correcting when a correction has to be made. Suppose an electrical relay controller set for "700 degrees." So long as the temperature is "exactly 700," the controller remains inoperative, and no command is transmitted from the controller to the motorized valve.* Not until a deviation from the normal condition of "exactly 700°" occurs need the controller act. Furthermore, the controller is so designed that it will not act until a deviation occurs. Finally, the controller will not act until its primary system responds to a measurable deviation. In other words the normal condition of "exactly 700°" is in reality 700° plus or minus the departure which causes the controller to act. This performance characteristic is true of all temperature controllers. The sensitivity of the primary system of an automatic controller thus emerges as a most important factor: an important *property* of the measuring system manifesting itself as an important *operating characteristic* of the control instrument.

It is generally necessary to distinguish between the sensitivity of the primary system and the corresponding characteristic of the control instrument, for two reasons: (1) that a small change may displace the pointer (or equivalent element) of the primary system of many widely employed forms of control instruments without causing any correction to be made; and (2) that while the sensitivity of the primary system is seldom variable at will, that of the controller may be adjusted. For example, the primary system of a particular electric-contact type temperature controller, *considered as a measuring instrument*, has a unit sensitivity of 5°F. so that a change of 5°F. will cause a displacement of 1 mm. at the tip of its pointer, but the controller may purposely have been set with "high" and "low" contacts separated by an angle corresponding to 20°F. To the question "what is the sensitivity of this thermostat?" there cannot be a simple answer. One might express the unit sensitivity of the primary system as 5°F. or express the ultimate sensitivity of the primary system as 2°F. (see Chap. II, Sec. 2) One might state on the other hand that while the controller is now set for 180° with high contact at 190° and low contact at 170°, it could be set for a smaller or a greater differential, the limits imposed by its design being, say, 10° for the smallest differential and 100° for the greatest.

This example illustrates both that the ultimate sensitivity of the primary element may not always be *utilized*, and that the minimum change causing corrective action by the controller is an always *greater* amount, which however may be varied at will in some designs.

*We purposely take the case of an electrically operated controller that literally *does nothing* when the controlled condition is correct. In the case of an air-operated controller, the constant flow of air suggests a continuous activity on the part of the controller which is irrelevant to the illustrative argument.

In this example of a contact thermostat it has been assumed for the sake of simplicity that whenever either the "high" or the "low" contact circuit is closed the controlled supply valve will be positively operated, so that it was not necessary to take into account the operation of the valve-operating mechanism. In the case of some other controllers the minimum departure necessary to cause motion at the instrument end of the primary system may not be sufficient to cause a change in the position of the controlled heat-supply valve. This is generally true of multi-element automatic controllers.

We may then make a distinction between the ultimate sensitivity of the control instrument and the minimum change which will cause a greater or smaller flow of the controlled medium, or otherwise cause effective action at the point of control. This performance characteristic of the control system *as a whole* is called Sensitiveness.*

The sensitiveness of a controller is expressed in degrees of temperature, as is the ultimate sensitivity of a temperature measuring instrument, but it is a different thing. Ultimate sensitivity has to do with a change of value anywhere within the scale range of a measuring instrument, but sensitiveness has to do only with changes in the region of the setting point. Ultimate sensitivity is usually a definite minimum amount of change in the measured temperature while sensitiveness is the sum of two amounts: one representing the ultimate sensitivity of the measuring system and the other representing the additional change in the controlled temperature necessary to cause effective action at the point of control. To illustrate this important difference we may consider an automatic temperature controller consisting of the following:

A. The primary measuring system which we may call the thermometer.

B. A remote reading system consisting mainly of a transmitter actuated by the thermometer and a panel board receiving instrument with setting dial for automatic control;

C. A relay system for energizing the power device;

D. The power device consisting of a reversing motor with limit switches and other usual accessories; and finally

E. The controlled valve operated by the power device.

Without going into details it is obvious that

1. The ultimate sensitivity of the measuring system is the change in temperature which will cause effective motion at the thermometer end.

2. A greater change is required to cause, at the panel board instrument, observable displacement of the pointer or pen arm or effective actuation of the prime relay.

3. The controlled temperature may fluctuate over a zone greater than the value of the ultimate sensitivity of the measuring system, without causing any relay to be actuated. This holds true even for the case that the controller is set for "point control" and not for "high and low."

4. As long as no relays are actuated and the controller remains inoperative, the controlled temperature is *normal*.

5. Normal temperature does not have a single value as does a "point."

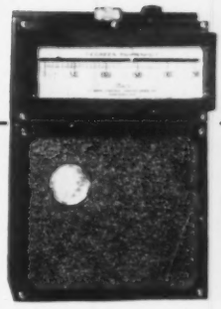
6. The controller's sensitiveness is the width of this zone.

Let us now assume that the ultimate sensitivity of the measuring system (when the temperature is around 500°) is 2° and that the sensitiveness of the controller is 5°. We then have a controller "sensitive to" 5°. In the event that its working range is 0-1000° it may be said to be "sensitive to one-half percent of working range." If its setting range is 400 to 600° it may be said to be "sensitive to 2½%."

In any case, it is plain to see that in addition to the distinction between sensitivity and sensitiveness, there is a distinction between setting point and normality. Normality is not a point but a zone or range.

Set for point control at 500°, this controller will perform a corrective function whenever a change of 5° occurs. Assuming that the entire installation is such that corrective action is always effective, the temperature will never drop for long below 495° nor exceed for long 505°. Moreover, if the installation is correct, the controller will settle down to

*This is in harmony with the A.S.M.E. Power Test Codes, which use "sensitivity" for the property of instruments in the Instruments and Apparatus Code and "sensitiveness" for the performance characteristic of "the complete speed-responsive regulating mechanism" in the Code for Speed-Responsive Governors.



"Alnor" ELECTRONIC TYPE PYROMETER CONTROLLER

No motors, no depressor bars—no contacts

The Alnor is a simplified controller which operates on an electronic principle similar to a radio.

The pointer of the pyrometer carries a vane. Two similar condenser vanes are attached to the arm of the adjustable target. When the pyrometer pointer reaches the target setting, the pointer vane passes between the condenser vanes and causes a change in the capacity of the circuit which in turn actuates the switch controlling the heating current or fuel valve. A red eye tells whether the heat is on or off.

With no motors, contacts, depressor bars, there is no time lag in response and the utmost in ruggedness and durability is provided. *Write for bulletin No. 3197-A*

Illinois Testing Laboratories Inc.

Dont Guess Know

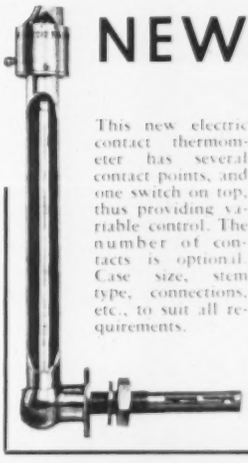
142 WEST HUBBARD ST., CHICAGO, ILL.

Look to "Philadelphia" for NEW as well as TIME-TRIED "Regular" Models

This new form has been designed to be used as both straight and angle thermometer. Five-inch scale; all "regular" stem lengths, ranges and connections.

One of hundreds of "regular" models of engineer type thermometers: 90° (degree) angle, with separable socket, 7", 9" and 12" standard case.

NEW



This new electric contact thermometer has several contact points, and one switch on top, thus providing variable control. The number of contacts is optional. Case size, stem type, connections, etc., to suit all requirements.

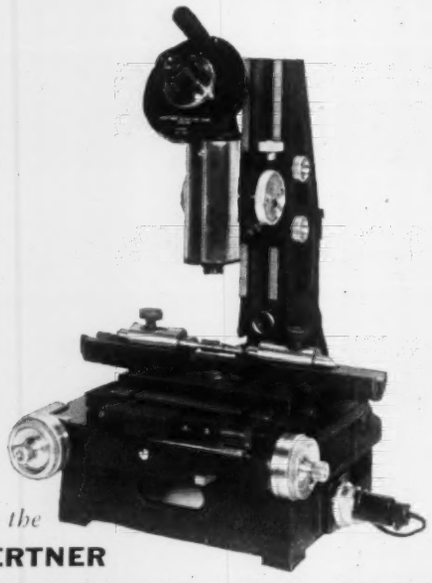
Instructive catalogs, presenting technical data on laboratory and plant instruments, will be sent on request.

The Philadelphia Thermometer Co.

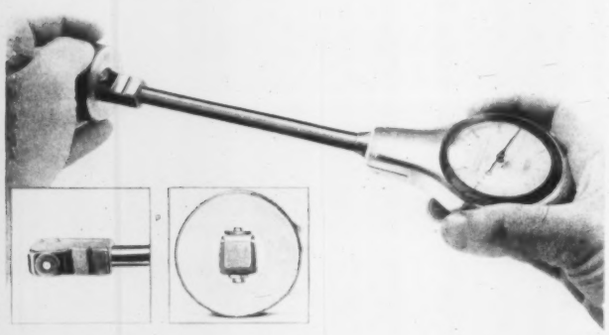
915 Filbert Street -:- Philadelphia

Oldest Thermometer Manufacturer in Philadelphia

Increase . . . **PRODUCTION**
Speed-Up . . . **MEASUREMENT**



With the
GAERTNER
TOOLMAKER MICROSCOPE
Descriptive Bulletin on Request
THE GAERTNER-SCIENTIFIC CORP.
1211 Wrightwood Ave., Chicago, U.S.A.



PRECISION for DEFENSE
REQUIRES MODERN TYPE GAGES
FOR CHECKING HOLES

Sensitive plug gages with Dial Indicators eliminate human variations. They are faster, show the facts as they are without that uncertain blind spot common to "go and no-go" gages, and tell more about tapered, out-of-round, and bellmouthed holes.

Work which would otherwise be scrapped can be sorted and saved to use with other parts. Federal Dial Indicator Gages are being used more and more in place of solid plug gages. Use them to speed up defense work.

FEDERAL PRODUCTS CORPORATION, PROVIDENCE, RHODE ISLAND

FEDERAL
PRECISION MEASURING INSTRUMENTS
Chicago • Cleveland • Detroit • West Hartford • Muncie
New York • Philadelphia • Pittsburgh • Rochester

the state where it functions at 497.5° and 502.5°. Normality in this case, is not identical with the setting point of 500 but is the 5° zone between 497.5° and 502.5°.

But this same controller—and this is true of many industrial controllers—may be adjusted to make contacts at 480 and 520° in order to save wear and tear on the power device, control valve and other accessories. Normality will then be a zone of 40°. The *actual sensitiveness* of the controller will be 40°, but the available sensitiveness, as could be determined in a test, will nevertheless remain 5°. And, of course, the sensitivity of the measuring system will remain 2°.

Now let the instrument-using reader imagine himself in the position of the instrument maker. It is a ticklish business to guarantee that the controller *will* maintain temperature within a maximum variation of ±5°, because the results obtained with any controller depend on the installation as a whole, including the application factors external to the controller. It will be simpler to overlook the difference between sensitivity and sensitiveness and, knowing that the thermometer has an ultimate sensitivity of 2°, to advertise that the controller is "sensitive to 2°." This common practice of controller manufacturers is not due to shrewd taking advantage of the fact that the adjective for both sensitivity and sensitiveness is "sensitive" but it is due to the greater convenience and desirability of considering the limitations of the measuring system.

On the whole, the general figure of merit of a control system is necessarily determined by that of its primary elements. Other things equal, a temperature controller with a measuring system the ultimate sensitivity of which is 2° F. will be capable of closer control than another controller having a measuring system the sensitivity of which is 10° F. It is by no means unethical for a manufacturer to state that his control pyrometer is "sensitive to a change of 2° in the furnace temperature"—and it is highly informative. It is a mark to shoot at in applying such a controller to a furnace.

"Sensitiveness," "normality" or "differential"—these standard Instrumentation terms are correct, both technically and in their implication. Some engineers in the employ of controller manufacturers use "dead zone"—which is bad because it sounds bad. At present (1932), instrument-department heads and other industrial experts wisely resist its introduction. Once they (the buyers) start using it when talking to manufacturers' engineers, they (the ones who now propose it) will be put on the defensive by the bad sound of this term. Some of them will then say: "Oh, but *our* controller has *no* dead zone!" It will be proved later that there is no such thing as an automatic temperature controller without dead zone. Since no temperature in industry need be maintained within a millionth of a degree, there is in every process a zone of normality. To maintain this normality, the controller has a corresponding normality or differential or sensitiveness of its own. That's all users want, but put "dead-zone" in their mouth and they'll want that which is as unattainable as . . . well, as measuring an industrial temperature closer than the International Temperature Scale.

In no case, of course, can a controller react to a departure smaller in value than the value of its sensitiveness. But—as the reader knows full well—this does not mean that a controller effectively sensitive to a given amount of change in the controlled temperature will necessarily be capable of controlling this condition within limits of departure equal to the value of such sensitiveness. In most cases the reason is that the installation does not meet the second and third of the Four Requirements stated in Sec. 4 but even when these requirements are satisfactorily met, we often find the record of the controlled temperature to be of the "saw tooth" variety with the difference between peaks and valleys many times greater than the departure from normality which makes the controller operate to effect a correction.

When we analyze installations we always find the causes of unsatisfactory control to involve *time elements*: "lags," "periods" and "delays." There never is any exception!

(To be continued)

For All **SCIENTIFIC** *Uses*

GALLET

GUINAND

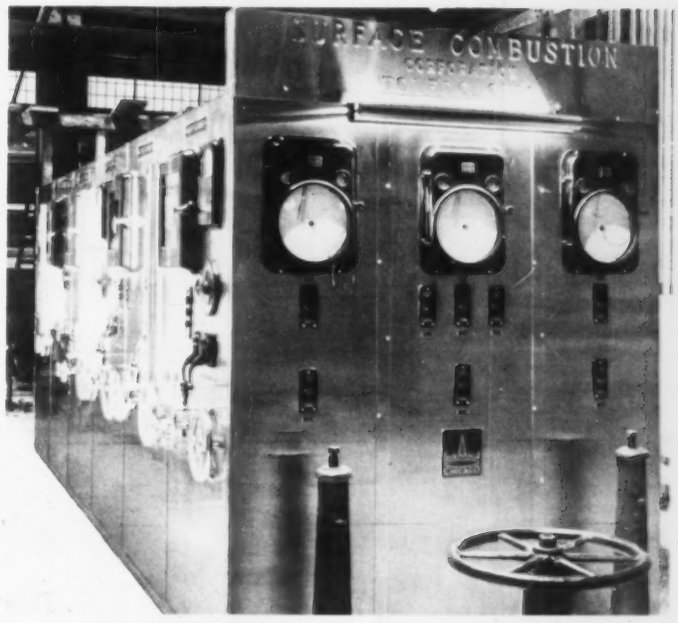
and **SECURITY**

TIMERS

The Widest Selection of **TIMERS** and **CHRONOGRAPHS** Best Quality in every Price Range

FREE *Catalog on request*

JULES RACINE & CO.
20 WEST 47th ST., NEW YORK



If you could stand here

IN some men the recognition of quality in mechanical equipment is instinctive—a sort of extra sense, born in them and sharpened up by practical experience.

Fact is, you are probably one of them yourself . . . and so we wish you could stand in front of this handsome stainless steel panel board that houses the Askania Control of two, 4-zone oil- or gas-fired slab heating furnaces.

You would see the signs of quality that you know so well—of sound-basics interpreted in masterful design and carried out in precision workmanship. And if you could watch the operation of this or any other Askania installation day after day you would recognize the maintained accuracy and freedom from maintenance that distinguishes Askania.

Askania regulation covers all phases of automatic control for all industries—combustion control, flow control, proportioning control and many others. Write for latest bulletins.

Askania Regulator Co., 1605 S. Michigan Ave., Chicago, Ill.

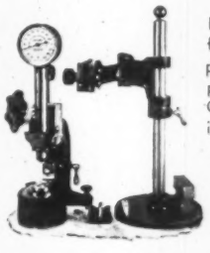
●Our plant facilities have been expanded so that our participation in the National Defense Program does not interfere with prompt execution of orders for industrial control equipment.

ASKANIA CHICAGO *Automatic* **CONTROL**

"IF IT CAN BE MEASURED—WE CAN CONTROL IT"

HARDNESS TESTING...

done WITH NO MENTAL HAZARDS. The SCLEROSCOPE has done it for the past 33 years.



In general use for specification purposes. Simple, sturdy. Comparatively inexpensive.

Illustrated bulletins free.

The Shore Instrument & Mfg. Co., Inc.
9025 Van Wyck Avenue, Jamaica, N. Y.

IT'S EASY TO SAVE MONEY WITH VARI-TYPER

Compose copy for your bulletins, sales manuals, booklets, catalogs, folders, etc., in *your own office* on the composing Type Writer with changeable faces and spaces. Any competent typist after proper instruction can Vari-Type your work to stencil, metal plate or photo-offset master copy with *large savings and improved appearance.*

● *Write Today for new specimen portfolio* "How to Profit by Using Vari-Typer" with actual samples of work produced.

RALPH C. COXHEAD CORPORATION
Manufacturers of Vari-Typer
333 SIXTH AVENUE NEW YORK CITY

★ *NATIONAL* ★
RHEOSTATS
Ask for Catalog No. 5
National Electric Controller Co.
5317 Ravenswood Ave., Chicago, Ill.

INDUSTRIAL INSTRUMENT SERVICE
CLAUD S. GORDON CO., Cleveland—Chicago—Indianapolis

LITTELFUSES—*"Quicker than a short circuit"*
Instrument fuses for meters 1/200 amp. up. Hi-volt for transmitters, etc. 1,000 5,000 and 10,000 volt ranges, 1/16 amp. up. All types of Littelfuse for aircraft radio, auto, etc. and mountings. Neon testers and indicators. Write for catalog.
LITTELFUSE, INCORPORATED—4759 Ravenswood Ave., Chicago, Ill.